ARMY RESEARCH LABORATORY

Power Sources Focus Group – Evaluation of Plasma Gasification for Waste-to-Energy Conversion

by William R. Allmon and Ronald S. Pandolfi

ARL-RP-0403 **September 2012**

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NOTICES

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14. ABSTRACT

Energy is a mission-critical enabler for Intelligence and Defense Community facilities and operations, both domestic and abroad. To enhance mission capabilities, the Power Sources Focus Group has been examining alternative and renewable energy technologies. Converting waste into electrical power is attractive because it responds to another mission-critical need, waste disposal. From a small expeditionary force of a few soldiers to a large foreign or domestic installation, the needs for eliminating waste and generating electrical power are major drivers for logistical support and mission capabilities. Plasma gasification has many potential attributes for eliminating waste and generating electrical power. It can eliminate a wide range of waste types—including municipal, industrial, medical, and other hazardous feedstock—while extracting a higher energy content than current methods such as incinerators and conventional gasifiers. This report is a limited scope evaluation of the technical feasibility and operational utility of plasma gasification for eliminating waste and generating electrical power. It is based largely on information presented during a September 28, 2011, special meeting of the Power Sources Focus Group on Plasma Gasification. Where there are principal uncertainties, this report recommends research, testing, and follow-on evaluations.

15. SUBJECT TERMS

Plasma gasification, waste-to-energy, energy conversion, municipal solid waste (MSW), hazardous waste, gasification, plasma, contingency bases, alternative energy, renewable energy, energy, synthesis gas, syngas

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Power Sources Focus Group – Evaluation of Plasma Gasification for Waste-to-Energy Conversion

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Introduction

This report is a limited scope evaluation of the technical feasibility and operational utility of plasma gasification for eliminating waste and generating electrical power. It is based largely on information presented during a September 28, 2011, special meeting of the Power Sources Focus Group on Plasma Gasification. Meeting objectives included:

1. shared awareness of capabilities for plasma gasification to convert waste into energy;
2. evaluation of the benefits to be expected for the Intelligence and Defense communities and the environment; and
3. consideration of the best options for using current plasma gasification technology and recommendations for research and development to extend capabilities.

Participation in the meeting included representatives from government, industry, and academia with expertise on plasma gasification or mission needs that potentially could be supported by plasma gasification.

Energy is a mission-critical enabler for Intelligence and Defense Community facilities and operations, both domestic and abroad. To enhance mission capabilities, the Power Sources Focus Group has been examining alternative and renewable energy technologies. Converting waste into electrical power is attractive because it responds to another mission-critical need, waste disposal. From a small expeditionary force of a few soldiers to a large foreign or domestic installation, the needs for eliminating waste and generating electrical power are major drivers for logistical support and mission capabilities.

Plasma gasification has many potential attributes for eliminating waste and generating electrical power. It can eliminate a wide range of waste types—including municipal, industrial, medical, and other hazardous feedstock—while extracting a higher energy content than current methods

such as incinerators and conventional gasifiers. This report evaluates these attributes from the limited scope of Intelligence and Defense mission need, while considering other competitive factors including size, weight, complexity, and reliability. Where there are principal uncertainties, this report recommends research, testing, and follow-on evaluations.

Defense and Intelligence Community Needs

The Defense Community requires a great deal of energy to carry out its operations. As a result, energy security is critical. In the tactical land warfare community, the need for more electrical power has grown over the past several decades. The majority of this electrical power is provided by fossil-fuel-burning generators. Thus, an increase in power equates to an increase in fuel required. The Marines report in the 2011 *United States Marine Corps Expeditionary Energy Strategy and Implementation Plan,* "Bases-to-Battlefield," that their current infantry companies use more fuel than infantry battalions did 10 years ago. These changes are driven by a 250% increase in the number of radios, a 300% increase in IT/computers, a 200% increase in the number of vehicles, a greater than 75% increase in vehicle weight, and a 30% decrease in miles per gallon across the tactical fleet.

Development of locally derived fuels and more efficient ways of utilizing fuels can help. Back in July 2008, a report from the Defense Science Board Task Force on DoD Energy Strategy, "More Fight – Less Fuel," suggested:

> [The] Director of Defense Research and Engineering (DDR&E) [should] initiate a research program to identify the characteristics of synthetic fuels likely to be producible at deployed locations, and identify, or develop as needed, materials for use in propulsion systems compatible with that range of fuel types. Technologies to produce synthetic fuels on a small scale using indigenous feedstocks are under development, and the ability of deployed systems to use those fuels would be operationally advantageous. Locally available feedstocks could include kitchen and human waste, other biological materials or used motor oil.

Using local feedstocks and generating fuels locally has additional benefits. Fuel delivery is a burden; but more importantly, our enemies are using the supply lines as targets for attack using improvised explosive devices (IEDs) and other means. As a result, more forces and equipment are required for protection instead of being available to carry out other operations. Further, operations can become delayed while waiting for a fuel resupply. The option of using air and sealift versus overland routes can challenge weight and volume limits, and adds significant cost. Not to mention, the volatile cost of fuel increases the burden. The bottom line is the more fuel needed for tactical operations, the more lives lost. The Army Environmental Policy Institute's Sustain the Mission Project estimates that there is one U.S. military or civilian casualty for every 24 fuel resupply convoys. While improvements in technology have resulted in greater lethality of the force, they have also meant greater risk to our logistics trains. One alternative has been to pay others to transport fuel on our behalf, but this creates the risk of indirectly funding our adversaries. With this as a backdrop, there are many efforts underway to solve this problem.

Using waste as feedstock solves the critical problem of waste elimination. This issue is especially challenging for small forward contingency bases, where resources are scarce and backhaul difficult. There are several approaches to solid waste management, including source reduction, reuse and re-purposing, and destruction. A combination of these approaches is

employed where possible. In Afghanistan, the Natick Solider Research, Development, and Engineering Center (NSRDEC) reports 67% of the sites use burn pits, 25% use other means including backhaul, and 8% use incinerators. Using burn pits creates a potential health hazard. Concerning the rates of solid waste generation, there have been a few studies conducted on various niche situations. From these limited studies, we found that field food service alone generated 3-4 pounds per person per day of solid waste. In a study of a Force Provider system, each person generated 6.7 pounds per day. For Operation Enduing Freedom (OEF), planners allowed for 10 pounds per person per day. If the site had a PX or bazaar, this number increased to 18 pounds per person per day. It is believed that there is tremendous variability in the solid waste stream of a site, depending on location and mission. As a result, the U.S. Army Logistics Innovation Agency (LIA) is conducting a new study. They sought to study the solid waste of small forward-located contingency bases, but they were granted permission to study sites with 3,000 or more personnel. The results of the study are scheduled to be available in fall 2012. It is clear solid waste management needs to be improved.

Definitions

Due to the limited information available, this paper does not attempt to determine the best way to use plasma in a gasifier. Instead, this paper makes general comparisons of waste-to-energy (WTE) technologies and offers recommendations for future steps concerning plasma gasification.

Incineration

Typical incinerators involve combustion of feedstock (at ~900 °C) without restricting air flow, leading to oxidation of the feedstock. The output of the process is heat, gases, particulates, ash, and reduced waste volume. This is a mature technology with many commercial installations operating worldwide. It handles a wide variety of wastes. Incinerators are used for waste destruction, but can be used for WTE by using the heat generated to heat buildings, create steam for use in a steam turbine, or both. Variations in the feedstock necessitate the use of an auxiliary fuel source (often fossil fuel) to maintain heat. The flue gas contains toxic substances such as volatile organic compounds (VOCs), dioxins, and furans that need to be broken down. For VOC destruction, the U.S. EPA recommends that flue gases reach a minimum temperature of 870 °C, 0.75-second residence time, and proper mixing. For halogenated VOCs, the gases should reach 1100 °C, 1-second residence time, and the use of an acid gas scrubber on the outlet is recommended (EPA Air Pollution Control Fact Sheet, EPA-452/F-03-022). A similar standard exists in the European Waste Incineration Directive. To ensure compliance in cases where the energy content of the feedstock is low, incinerators are equipped with auxiliary burners, typically fueled by oil, to increase the temperature and deal with variations in the feedstock.

Gasification

Gasification is a process that converts a feedstock into synthesis gas ("syngas") without combustion by using a controlled amount of air and/or steam, leading to partial oxidation of the feedstock. The syngas can be used as a fuel in gas turbine generators or fed into the air intake manifold of diesel generators to offset diesel used to run the generator. Besides syngas, the

process creates other gases and ash requiring clean up. The process also reduces the volume of the waste. The heat generated by the turbine or generator, gasification, and other processes can be used to produce steam for a turbine, heat living spaces, or both. Gasification of fossil fuels is currently widely used on industrial scales to generate electricity. The feedstock can be organic or fossil-based carbonaceous materials. For waste as a feedstock, this technology is best suited for dry packaging waste, thus requiring manual separation and/or extensive feedstock conditioning such as drying. This process has the potential to be comparatively lightweight and low cost.

Plasma Gasification

Plasma gasification for the purposes of this paper includes any WTE system using plasma as part of the generation of syngas and/or cleanup of flue gases. Typically, a plasma system operates at higher temperatures than incinerators. It uses a limited amount of air and high-energy plasma to decompose the feedstock into syngas and wastes. The syngas can be used as a fuel in gas turbine generators or fed into the air intake manifold of diesel generators to offset diesel used to power the generator. The heat generated by the turbine or generator, plasma, and other processes can be used to produce steam for a turbine, heat living spaces, or both. The technology reduces the volume of the wastes, yielding principally gases and glassy slag. The gases are cleaned up through gas clean up equipment. The glassy slag is considered inert because it binds up the metals, heavy metals, and glass so it will not leach out. This process handles a wide variety of waste to include certain hazardous wastes with little feedstock conditioning. It does require electrical power input to sustain the plasma.

Technology Comparison

Some forms of energy are more useful on the battlefield than others. Certain WTE methods are better than others at producing desirable forms of energy. WTE technologies that produce syngas such as plasma gasification, downdraft gasification, and others can be used to make electricity using gas turbine generators or fed into the air intake manifold of diesel generators to offset diesel used to power the generator as noted above. Using standard Tactical Quiet Generators (TQGs) or other military generators will minimize the logistics and maintenance burden. Electricity is useful because one can connect generators to a micro-grid to ensure demand for all power generated.

Another form of energy from a WTE system is heat. Plasma gasification, gasification, and incineration all produce heat. Unfortunately, this is less desirable because it is difficult to align with demand. Heat generation creates issues of where to locate WTE systems within the camp or creates the need for heat transfer devices.

Another form of energy is liquid fuels. Syngas generated from plasma or other gasification methods can be synthesized through a Fischer-Tropsch process to create liquids that meet JP-8 specifications. Unfortunately, much energy is lost in the synthesis. Other WTE technologies create biofuels such as ethanol or pyrolysis oils, which are not approved to use in battlefield equipment and thus have little value.

Plasma gasification is feedstock flexible compared to other gasification processes. Plasma gasification systems have processed hazardous wastes such as low grade radioactive, medical, electronic, PCBs, batteries, asbestos, and toxic chemicals. The higher operating temperature makes it better for treating toxic substances than other gasification technologies. Lastly, heavy metals such as arsenic, mercury, chromium, cadmium, lead, and others get bound up in the chemically inert slag. This slag can be landfilled or repurposed for road beds or fill. With gasifiers, the ash is considered a hazardous substance since the heavy metals can leach out.

There are several advantages in using plasma gasification systems over incinerators:

- Plasma gasifiers operate at higher temperatures than incinerators, resulting in **better treatment of toxic substances.**

- Plasma gasifiers use a limited amount of air compared to incinerators, so there is **less waste gas to treat.** It is estimated that plasma gasifiers have only 10% of the volume of waste gas compared to incinerators. As a result, the gas cleanup equipment can be smaller.

- Unlike incinerators, plasma gasifiers **generate syngas,** which is useful as a fuel. Using syngas is potentially more efficient than direct combustion of the original fuel, because it is combusted at a higher temperature. Thus, the thermodynamic upper limit to efficiency (Carnot efficiency) is higher. This must be balanced with overall system efficiency, as a significant amount of power is required to create the plasma.

- Plasma gasifiers **do not require fuel,** whereas incinerators require fuel to run an auxiliary burner. This need for fuel adds to the size and weight of the system and increases operating costs (*Studies on the Application of Plasma Arc Technology to Destruction of Shipboard Waste*, B.D. Sartwell et. al, NRLIMR/6170--99-8353, page 12, Naval Research Lab, 1999).

- Lastly, with incinerators, the ash is considered a hazardous substance.

According to the EPA Air Pollution Control Fact Sheet, EPA-452/F-03-022 incinerators have other disadvantages:

- Thermal incinerator operating costs are relatively high due to supplemental fuel costs.

- Thermal incinerators are not well suited to streams with highly variable flow because of the reduced residence time and poor mixing during increased flow conditions, which decreases the completeness of combustion. This causes the combustion chamber temperature to fall, thus decreasing the destruction efficiency.

- Incinerators, in general, are not recommended for controlling gases containing halogen- or sulfur-containing compounds because of the formation of highly corrosive acid gases. It may be necessary to install a postoxidation acid gas treatment system in such cases, depending on the outlet concentration.

- Thermal incinerators are also not generally cost-effective for low-concentration, high-flow organic vapor streams.

There are several disadvantages of plasma gasification. From our research and discussion with industry, plasma gasification systems are likely most efficient in large scale beyond the size of interest for tactical operations. The ability of the technology to scale down efficiently is unknown. In addition, consumables such as water, sand, lime, and certain gases may be required, depending on system design. Providing consumables to tactical locations creates logistics problems. Also, this technology requires more input power compared to other gasification systems. While industry claims to have systems that are net energy producers, it has been difficult to independently determine the process efficiency and net energy production due to limited access to industry data. In addition, the process is complicated to model. These issues, along with the industry's proprietary information controls, make it difficult to verify claims of accurate models or overall system efficiency.

Projects using plasma gasification tend to be large, making it hard to research without significant investment. There are few domestic commercial systems in operation, making it difficult to evaluate the technology. Financial incentives for commercial Municipal Solid Waste (MSW) WTE may not drive this solution, as it is difficult to compete with the low cost of landfilling. Also, incinerators are less expensive, and there are many in operation in the commercial world. Plasma gasification systems, with their high temperatures and additional equipment, are potentially more expensive than other gasification technologies. The financial incentives change when considering hazardous wastes. The balance between the ability to process hazardous wastes and feedstock flexibility need to be weighed when considering Defense and Intelligence Community requirements. As of now, the requirements from the Department of the Army have not been solidified.

Below is a sample calculation based on data provided by the Noblis Forward Operating Base (FOB) Report. Given the potential energy content of the waste, how much waste is generated per person per day, the size of the force, the energy required per person, and an estimate of WTE system efficiency, it appears for a 550-person Force Provider module, power for 9 people could be generated. For a platoon FOB, power for three people could be generated. Efficiency is a big question with plasma technology. In addition, the extra logistics of the system and any consumables required must be considered.

For a 550-person Force Provider Module:

- 3,707 kcal/kg = 15,510 kJ/kg = energy content of waste per kg

- Using 4.1 pound/person/day = 1.86 kg/person/day

- 15,510 kJ/kg × 550 people for a Force Provider Module × 1.86 kg/person/day × 1 day/86400 sec = 184 kJ/sec or kW

Thus, the Force Provider module requires 1.1 MW of continuous power or about 2 kW/person.

If the WTE system is 10% efficient, the system will generate 18 kW, which supports nine people using a Force Provider Module.

For a Platoon-sized FOB:

- A Platoon FOB in Afghanistan needs 20 kW for 25–50 soldiers, which equals 0.5 to 0.8 kW/person. This excludes heating and cooling, which is a significant load.

- 15,510 kJ/kg × 50 people × 1.86 kg/person/day × 1 day/86400 sec = 16.7 kJ/sec or kW

Thus, if the WTE system is 10% efficient, the system will generate 1.6 kW, which supports three people at a Platoon FOB.

It is still uncertain as to what efficiency might be achieved in a Force Provider or Platoon-sized plasma gasifier.

Performance Barriers: Battalion-scale Waste to Energy (WTE)

NSRDEC has been working on WTE technologies in support of Force Provider and Battalion-scale sustainment systems for seven years. They have pursued and demonstrated feasibility of downdraft gasifiers, but several performance barriers remain, including: systems being too large and/or too heavy; systems being too expensive and/or poor Return On Investment (ROI); and having limited feedstock supplies. It is the feedstock limitations of the downdraft gasifiers that motivated this evaluation of plasma gasification systems as a potential solution.

According to NSRDEC, successfully addressing these challenges should result in systems suitable for widespread deployment. No major breakthroughs are expected without Government investment; there is comparatively little demand in the commercial sector because land-filling is so inexpensive, and the ROI is highest where the fully burdened cost of fuel or waste is high. NSRDEC also points out that fuel savings will be small compared to today’s total fuel demand from a Force Provider-supported camp. WTE technologies should be considered as one piece of a holistic approach to reducing the logistic bootprint of deployed forces. In addition, WTE benefits can be maximized by using it wisely, such as connecting the output to a microgrid to ensure demand for all electrical power produced while also providing surge capacity for power-hungry subsystems (such as shredders). Also, the system should be operated as a combined heat and power device using the “waste” heat for space or water heating. Lastly, NSRDEC mentions the cost savings will always be most substantial where the fully burdened cost of fuel and/or waste disposal is high.

Government Experience with Plasma Gasification

PyroGenesis Canada developed Plasma Arc Waste Destruction System (PAWDS) for the Navy. The Navy began work in the late 90s when plasma technology was selected, because it was the best technology for waste size reduction. The systems will be installed on the new nuclear aircraft carrier, where there is plenty of electrical power to operate the system. The system is not designed to produce energy but rather to reduce the size of waste. It has a capacity to process 5

tons of waste per day. The controls took years to develop to ensure minimal operator and maintenance training was required as well as ensure maximum safety.

PyroGenesis Canada also developed the Plasma Resource Recovery System (PRRS) for the Air Force Special Operations Command (AFSOC) at Hurlburt Field, FL. This system was designed to process 11 tons per day including MSW, medical, and certain hazardous wastes while being energy neutral. Unfortunately, it has not performed at this level to date. The system is undergoing improvements, most of which do not involve the plasma portion. For more details, see Appendix 3.

Industry Experience with Plasma Gasification

According to Gershman, Brickner, and Bratton (GBB) in their "Waste-to-Energy and Conversion Technologies Status Report" presentation June 14, 2011, 47 companies are offering technology and/or development services involving plasma gasification. GBB also reported that just two of the 58 conversion locations claiming to be operating domestically and commercially with MSW use plasma gasification. GBB considers gasification technology high-risk due to limited operating experience at only small scale and the potential for scale-up issues.

Many factors play into success of a project: project management; permitting; confusion with incineration (e.g., pollution problems with incinerators, local populace push back, the "Not In My Back Yard [NIMBY]" problem); feedstock variations and availability; low cost of landfilling; variable cost of fossil fuels; and investors' whims. The history of the plasma gasification business is checkered with projects that run for short durations, projects that go bankrupt (though not due to technology), and projects that are broken down and moved due to changes in feedstock availability. Currently, there are many projects scheduled to come online soon from several industry players. Finally, there are many intellectual property issues within this industry, making evaluation of the technology difficult.

Requirements and Baseline

The Department of Defense (DoD) has unique needs and high costs for fuel and waste management at the *tactical level*. Unfortunately, limited data exist about waste streams from Contingency Bases. There are no data available for small tactical bases, where disposal of waste is most difficult. It is critical to characterize the solid waste streams, since the energy produced is dependent on feedstock. The feedstock has a measureable energy and moisture content. As the moisture increases, the energy content per pound is reduced and more energy is required to pre-process (dry) the wastes. Besides solid waste streams akin to MSW, hazardous waste creates other issues. The Army has not finalized the requirements for WTE. There may be a need for unique requirements for individual Contingency Bases, depending on their sizes and missions. Another issue is how much sorting (if any) can be mandated or expected.

Conclusion/Recommendations

As a result of the Power Sources Focus Group plasma gasification workshop, it was determined that plasma gasification technology has potential uses for basing operations, and funding was provided to conduct independent demonstrations and evaluations of existing plasma gasification

systems offered by several manufacturers. This will allow a comparison of the results with other independently demonstrated and evaluated WTE technologies. These demonstrations and evaluations will determine the performance and accuracy of plasma gasification system models used in system design. Each system will be tested *in situ* with all system inputs and outputs measured to determine energy balance. The focus will be to: determine the state of plasma gasification technology as it currently exists; determine the limitations and potential areas of further research; and compare it with competing technologies.

For various sizes and missions of military Contingency Bases, a study is recommended to characterize solid waste streams to determine the materials, energy, and moisture content. The performance of plasma gasification and other WTE systems is highly dependent on the feedstock. The energy content of the constituents of the waste stream can vary widely. Metals and glass add nothing to the energy content and reduce the efficiency of WTE systems due to the energy wasted on melting these materials. Although Contingency Bases vary widely, we recommend that a limited number of theoretical waste stream models be developed that represent the range of typical waste streams found for variously sized and missioned bases. The following are the size ranges of interest: small tactical bases of up to 300 people; Battalion-sized bases (300 to 1200 people); Brigade-sized bases (2,500 to 4,000 people); and large bases (more than 4,000 people). Some typical missions might be infantry, artillery, armor, aviation, maintenance, logistic, village stability operations, others, or a combination of the above. These models should be used to evaluate the performance of WTE systems and to help create requirements documents. In addition, a concept of operations (CONOPS) needs to considered. A minimum amount of sorting of waste, such as metal and glass from other constituents, will help the efficiency of WTE systems.

Plasma gasification systems may prove useful for waste destruction. In the commercial world, some plasma gasification plants process hazardous feedstocks, such as low grade radioactive, medical, electronic, PCBs, batteries, asbestos, and chemical wastes, which are difficult and/or expensive to dispose of. Other feedstocks, such as agricultural waste, industrial waste, MSW, and others, may not prove commercially viable for processing via plasma gasification because the cost of land-filling these wastes is so low. In many Defense and Intelligence applications, waste disposal is very expensive and/or dangerous. The economics of commercial and domestic waste disposal are quite different than those in theater, making plasma gasification more attractive. It would be helpful to better define the fully burdened cost of fuel and the fully burdened cost of waste to help evaluate the value of this and other WTE technologies.

Evaluation of plasma gasification systems may prove to be difficult. There are many ways to design a system. In addition, research-sized plants do not necessarily scale up and the efficiencies of large plants are difficult to achieve on research-scale plants. Also, system equipment and operational costs and environmental permitting add to the difficulty. Finally, some operating plants are located OCONUS, making site visits inconvenient.

Appendix 1– Meeting Agenda

Power Sources Focus Group

Meeting on Plasma Gasification for Waste to Energy

September 28, 2011

Registration

0830 – 0900 ARL Badging Office, Building 205

Introduction

0900 – 0910 Ron Pandolfi

Session I – Defense, Intelligence, and Civil Needs

Chair – Bill Allmon

0910 – 0950 Don Pickard and Leigh Knowlton – Baseline & Tactical Army Needs

0950 – 1000 Franklin Holcomb – Installation Army Needs

1000 – 1010 Jim Mann – Navy Needs

1010 – 1020 Aliyah Pandolfi – St Kitts Energy Project

1020 – 1030 Dan Smith – Civil (Maryland) Needs

Break

1030 - 1045

Session II – Recent Government Experience

Chair – Ron Pandolfi

1045 – 1115 George “Ron” Omley – Plasma Resource Recovery System (PRRS)

Session III – Academic Perspectives

Chair – Ronald Besser

1115 – 1145 Ronald Besser – Physics/Chemistry of Waste-to-Energy Conversion

1145 – 1215 Greg Jackson – Physics/Chemistry of Plasma Gasification

1215 – 1300 Lunch

Session IV – Industry Perspectives

Chair – Tom Rendall

1300 – 1345 Dennis Miller – Solena Group

1345 – 1415 Gillian Holcroft – Pyrogenesis

1415 – 1445 Gabriel Jebb – Adaptive Arc

1445 – 1515 Jeff Surma – InEnTec

1515 – 1545 Benjamin Tongue – Lockheed Martin

Closing Remarks

1545 – 1600 Bill Allmon

Session V – Government Only Discussion and Planning

Appendix 2 – Presentations

Defense, Intelligence, and Civil Needs

Waste-to-Energy Conversion for Small Contingency Bases
Don Pickard and Leigh Knowlton, *US Army Materiel Command, Natick Soldier RD&E Center*

Army Net Zero Initiative and Waste-to-Energy Opportunities
Franklin Holcomb, *US Army Corps of Engineers, Engineer Research and Development Center*

St. Kitts Energy Project
Aliyah Pandolfi, *Al-Kareem Foundation*

Recent Government Experience

Plasma Waste-to-Energy System: Hurlburt Plasma Project
George “Ron” Omley, *USAF Special Operations Command, Asset Management Division*

Academic Perspectives

Perspectives on Plasma Gasification for Waste Processing and Energy Consumption
Ronald Besser, *Stevens Institute of Technology*

Plasma Gasification: Research Challenges and Needs
Greg Jackson, *University of Maryland*

Industry Perspectives

Introduction to Zero Emissions Bio-Energy
Dennis Miller, *Solena Group*

Innovative Plasma Waste-to-Energy Solutions
Gillian Holcroft, *PyroGenesis Canada*

Introduction to adaptiveARC
Gabriel Jebb, *adaptiveARC, Inc.*

Deployable Omnivorous Plasma-Assisted Gasifier (DOPAG)
Benjamin Tongue, *Lockheed Martin*

Appendix 3 – Responses to Queries

Defense and Intelligence Community Needs, Defense and Intelligence Community Experience, Academic Perspectives, and Industry Perspectives
Gabriel Jebb, *adaptiveARC, Inc.*

Defense and Intelligence Community Needs, Defense and Intelligence Community Experience, Academic Perspectives, and Industry Perspectives
PyroGenesis Canada

Defense and Intelligence Community Needs and Defense and Intelligence Community Experience
Mark Leno, *US Army Logistics Innovation Agency*

Academic Perspectives
Roland S. Besser, *Stevens Institute of Technology*

Academic Perspectives
Sven Bilén and Stewart Kurtz, *Penn State University*

Waste to Energy Conversion for Small Contingency Bases

Power Sources Focus Group

Meeting on Plasma Gasification for Waste to Energy

28 September 2011

Don Pickard
Power and Energy Lead for Contingency Basing
US Army Natick Soldier RD&E Center

US ARMY RDECOM

US ARMY NATICK SOLDIER RD&E CENTER

Goals of This Briefing

- Objective:
  - Share NSRDEC perspectives on Waste to Energy Conversion for small base camps (100-1000 personnel)
- Topics:
  - Contingency Basing
  - Problem Discussion
  - NSRDEC Work
    - Past, Present, and Future
  - Other Relevant Efforts
  - Technical Challenges
  - Energy Balance

Contingency Basing
and
Logistics Reduction

Contingency Basing
Example Patrol Base / Combat Outpost

When you've seen one base camp…

You've seen one base camp.

Force Provider
Life Support for Army Bare Bases

Force Provider Basics

- Force Provider is the critical life support element for Army bare base camps
- Force Provider supports 550 personnel (+50 operators) with:
  - Climate Controlled Billeting
  - Quality Food Service (1800 meals/day "A" rations)
  - Laundry Service (200 lbs/hour)
  - Showers & Latrines (one 10 minute shower/day)
  - Morale, Welfare and Recreation Facilities
- Power, 24 60kW TQGs (1.1 MW Continuous)
- Water Storage & Distribution (80K gals/3 days)
- Fuel Storage & Distribution (20K gals/3 days)
- Waste Water Collection (30K gals/day)
- System Support Packages—30 days repair parts
- Transportable—air, rail, land, sea (containerized)
  - ~81 TRICONs, 10 ISOs and rolling stock

Force Provider
Daily Usage Data (600-man)

System	Capacity	Power	Fuel (gal/day)	Water Supply (gal/day)	Greywater Produced (gal/day)	Blackwater Produced (gal/day)
Containerized Latrine System (CLS)	Four CLSs per module each with 6 commodes, one urinal and a two bay sink	38 kW	n/a	2700	n/a	3465
Containerized Batch Laundry (CBL)	200 pounds/hour	100 kW	25	5200	5200	n/a
Containerized Shower System (CSS)	Two CSSs per module, each with 12 stalls, avg 10 minutes/ shower per person per day	55 kW	12	11000	11000	n/a
Food Service Facility	1800 A meals per day	120 kW	25	1925	1375	n/a
Power Generation	27 60kW-TQGs, 18 operating at all times; 1,080 kW	n/a	2186	n/a	n/a	n/a
	TOTAL	**313+**	**2248**	**20825**	**17575**	**3465**

Trash: Approx. 2500 lbs per day

Contingency Basing
Sustainability / Logistics Vision

Integrated, Waste, Water and Fuel Management Plan

Recycle

Reuse & Repurpose

Key Stakeholders:
TRADOC (MSCoE, SCoE, MCoE), ASAALT, G8, COCOMS

Key S&T Partners:
ERDC, ARL, TARDEC, CERDEC, NSRDEC, AMSAA, Industry

50% Waste Reduction

75 % Water Reduction

25% Fuel Reduction

Key Transition Partners:
PM-FSS, PM-MEP, PM-PAWS

Small COP to Small FOB
100-1000 Pax

Contingency Basing
Solid Waste Reduction

- Approaches for waste reduction:
  - Source Reduction
  - Reuse and Re-purposing
  - Destruction

  Waste to Energy

- Solid waste management in Afghanistan (by site, recent OEF data):
  - 67% burn pits
  - 25% other (incl. backhaul)
  - 8% incinerators
- Waste generation rate?
  - Field foodservice alone: 3-4 lbs/person/day
  - Force Provider: 2 TPD or 6.7 lbs/person/day
  - OEF planning:10 lbs/person/day, 18 with PX or bazaar
  - LIA is sponsoring a new study
- Current WTE does not meet mission requirements for 100-1000 man camps
  - NSRDEC Combat Feeding Directorate has been working this challenge for 7 years




Waste to Energy Conversion
as CB Logistics Reduction Initiative

Technical Problem	Current solid waste handling has negative impacts on mission (e.g., logistics, environmental, health, safety, energy, etc.). Solid waste streams represent potentially under-utilized resources.
Technical Barrier	Current small scale WTE is too large, expensive, and has significant feedstock limitations.
Capability Sought	WTE that converts mixed waste into electricity and minimal volume of benign byproducts. (>500 PAX)
Result / Product	Demonstration of WTE capability for camps >500 PAX. Objective of 90% reduction of organic waste and use of burn pits with net positive energy export.
Requirement	Capabilities Production Document (CPD) for Force Provider currently in staffing within TRADOC. Contains performance goals as objective requirements. Also: • Capabilities Based Assessment for Contingency Basing completed my MSCoE in 2011 - Joint ICD being developed • Operational Energy Initial Capabilities Document (ICD) currently in Joint Staffing
Acquisition Program	Force Provider (Contingency Base Life Support System) procured and fielded against OCO requirements. Long term procurement plan/funding not clear.

Waste to Energy Conversion
Useful Energy = Electricity

Electricity	• Connect to micro-grid to ensure demand for all power generated • Possibility of using standard TQGs to minimize maintenance burden
Heat	• Comparatively efficient and technologically easy • Less desirable because difficult to align with demand (location within the camp, need for heat transfer devices)
Liquid Fuels	• Fischer-Tropsch liquids can meet JP-8 specifications, but much energy is lost in the synthesis • Biofuels such as ethanol have little value as a battlefield fuel (also true for pyrolysis oils)

Waste to Energy Conversion for Small Contingency Bases

Power Sources Focus Group
Meeting on Plasma Gasification for Waste to Energy
28 September 2011

Leigh Knowlton
Equipment & Energy Technology Team
Combat Feeding Directorate
US Army Natick Soldier RD&E Center

Waste to Energy Conversion at NSRDEC

Where we've been…

Background

TODAY: Waste is a Liability

- Waste disposal is an expensive logistical burden

VISION: Waste is Power

- Paradigm shift—waste is less a liability, more a resource
- Convert waste into energy for organizational equipment

Energy Potential of Field Feeding Waste

- A Force Provider supported camp generates 1–2 tons of waste each day
- Most of the trash is carbonaceous—a potential fuel source

90 lbs
mixed waste

has energy content equivalent to…

5 gal
JP-8

…and about half can be recovered

Waste generated feeding 300 troops a single UGR™ dinner

Need

- Deployed forces produce enormous amounts of waste that must be disposed at great expense
  - 3–4 pounds/person/day of field-feeding waste
  - A 550-man Force Provider camp produces more than 1 ton/day field-feeding waste
  - Currently waste is usually disposed in burn pits
  - Most waste is carbonaceous and therefore a potential energy source
- The purpose of this effort is to develop and demonstrate technologies that treat solid waste as a resource, producing useful energy (primarily electricity) while minimizing field waste
- The ROI / Payoff of this effort is reduced logistics and improved safety for the Warfighter, while protecting the environment
  - Reduce two costly burdens: waste & fuel
  - "Trucks off the road" = force protection
  - Reduces the use of hazardous burn pits
  - Solid waste disposal is a key capability for Zero Footprint base camp goal

Waste Characterization Data

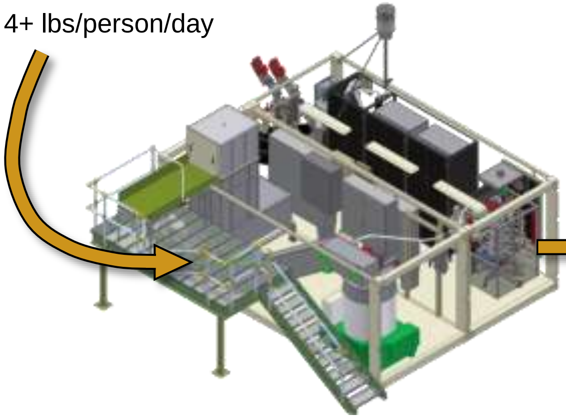
	Force Provider Training Module (Fort Polk, June 2000)	Army Field Feeding System (Fort Campbell, April 1995)	ASG Eagle Base Camp (excluding wood)	ASG Eagle Base Camp (including wood)	NDCEE Feasibility Study (including wood)	AF Bare Base (BEAR) (Estimated from PSAB data)	USS Nimitz (CVN 68) (April 2008)
Study Population	164	210	3700	3700		1182	4316
Paper & Cardboard	38%	45%	49%	12%	9%	53%	23%
Plastic	12%	8%	34%	8%	8%	26%	8%
Food	40%	14%	4%	1%	7%	2%	51%
Misc	7%	12%	8%	2%	4%	10%	13%
Metal & Glass	3%	21%	5%	1%	1%	6%	5%
Wood	–	–	–	76%	72%	3%	<1%
Per Capita (lbs/person/day)	4.1	3.2	3.0	12.6		13.2	3.7
Fuel Potential	97%	79%	95%	99%	99%	94%	84%

One more data point: **DARPA/LMI at NTC = 7.2 lb/day**
(data from six rotations during Sep 2002 – Apr 2003)

Field Feeding Waste to Energy Converter (WEC)

4+ lbs/person/day

Energy from Trash:
Sustainable Waste Reduction for Deployed Forces



Gas production module (containerized gasifier)

Producer gas displaces JP-8 in diesel genset

Purpose:

- Provide robust capability to convert field-feeding solid waste into electricity
  - Paradigm shift: waste is not a liability, but an energy resource
- Reduce logistics and improve safety for the Warfighter

Results/Products:

- Technical demonstration of WEC technologies suitable for Force Provider, large Combat Outposts, and/or small Forward Operating Bases
  - Packaged in 8×8×20’ ISO containers
  - Integrated gasifier, feedstock pre-processor, and electrical power generation capability
  - Improved gasifier technology for integration with future prototypes

ROI/Payoff:

- Reduce logistical burden of field feeding
  - Reduce two costly burdens: waste & fuel
  - “Trucks off the road” = force protection
- Transition to PM-FSS in FY12

Schedule

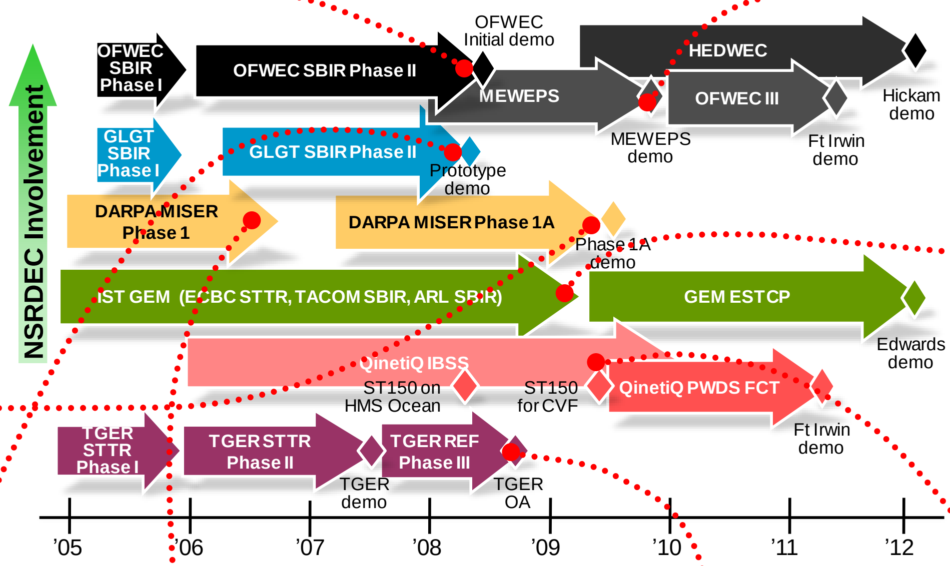
Milestones	FY05	FY06	FY07	FY08	FY09	FY10	FY11
DARPA MISER		4					
Develop Gasifier / WEC		4		5			
Develop Pre-processor			4	5			
Integrate System (MEWEPS)					6		
EQT Benzene Mitigation					4		
ARL HEDWEC System						5	
Upgrade MEWEPS							6
Demonstration							
Transition to PM-FSS							6
TOTAL $							

In Pursuit of the Solution…

Various inter-related efforts have been developing technology for battalion-scale waste to energy conversion, and a few leading candidates have emerged.

Community Power Corporation
Onsite Field-feeding Waste to Energy Converter

General Atomics
Supercritical Water Gasification



CPC & NextEnergy
Military Encampment Waste to Electrical Power System

InfoSciTex
Green Energy Machine

Green Liquid & Gas Technologies
Indirectly Heated Gasifier

Celltech Power
Liquid Anode Fuel Cell

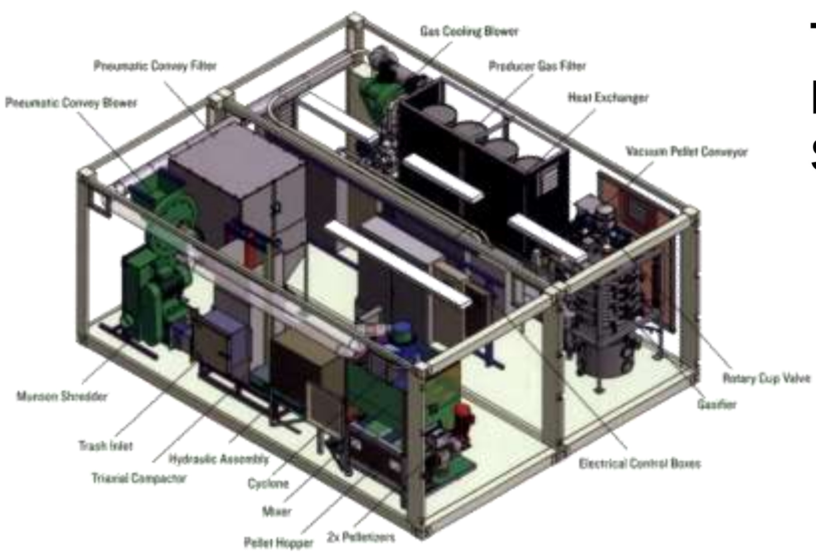
Defense Life Sciences
Tactical Garbage to Energy Refinery

QinetiQ
Pyrolysis Waste Destruction System

Past Efforts
(OFWEC, MEWEPS)

NSRDEC / CPC Onsite Field-feeding Waste to Energy Converter (OFWEC)

- CPC BioMax® Gasifier, 1200 lb/day
- One ISO container
- Interfaces with 60 kW TQG
- Handles only paper and plastic (no wet food)
- Shredded feedstock has proven problematic
- Reliable long-term operation not demonstrated



TARDEC / NextEnergy Military Encampment Waste to Electrical Power System (MEWEPS)

- CPC BioMax® Gasifier, 1200 lb/day
- Two ISO Containers
- Compared to OFWEC, adds gasifier design improvements and pelletizing pre-processor
- Designed for paper and plastic
- Demonstrated in 2009 at Camp Grayling, MI
- Upgraded into OFWEC III in 2010

Past Efforts
(TGER, IHP/G)

ECBC / DLScience Tactical Garbage to Energy Refinery (TGER)

- CPC BioMax® Gasifier + fermenter + pelletizer
- Included 60 kW diesel gen-set (ethanol and producer gas used to displace JP-8)
- Designed to handle foodservice waste (including paper, plastic, and food)
- Demonstrated in 2008 at Camp Victory, Iraq, with mixed results

NSRDEC / Green Liquid and Gas Technologies Indirectly Heated Pyrolyzer/Gasifier

- High-temperature pyrolytic gasification
- Demonstrated with MRE and UGR packaging
- Very small scale (company-level?)
- Would need ancillary equipment (shredder, gas and liquid cleanup, generator)
- Would need additional development and engineering

Past Efforts
(DARPA MISER)

DARPA / General Atomics Mobile Integrated Sustainable Energy Recovery (MISER)

- Supercritical Water Gasification
- 100 kW gen-set
- Prototype designed primarily for plastic feedstock
- Reliable operation and conversion goals not demonstrated

DARPA / CellTech Power Liquid Anode Fuel Cell

- Solid oxide fuel cell variant that uses a liquid tin anode
- Multi-fuel capability offered direct conversion of solid carbon (e.g., carbon black, graphite, coke, coal, biomass), gaseous fuels, and liquid fuels
- Effort completed without meeting DARPA energy density goals

Waste to Energy Conversion at NSRDEC

Where we are today…

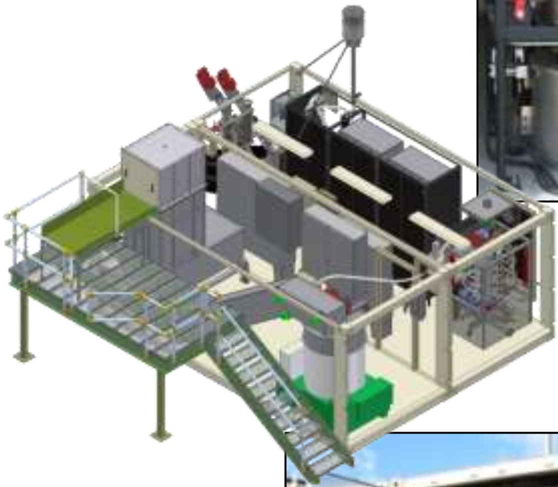
Community Power Corporation
(BioMax® Downdraft Gasifier)

Community Power Corporation
The Modular Bioenergy Company

- **Approach: BioMax® Stratified Downdraft Gasifier**
  - Innovative design with electronic instrumentation and active air controls to optimize the process
- **Reduces dry feedstock to fuel gas and char/ash**
  - The clean producer gas can be used in an internal combustion engine
- **Pre-commercial system designed to convert woody biomass into electricity and heat**
  - Markets include small industrial, agro-processing, and rural electrification

- ***<u>OFWEC</u>* SBIR Phase II demo in 2008**
- ***<u>MEWEPS</u>* demo in 2009 at Camp Grayling**
- ***<u>OFWEC III</u>* demo in 2011 at Net Zero Plus JCTD**
- ***<u>HEDWEC</u>* 2 TPD system to be delivered in 2012**

Typical BioMax® Gasifier

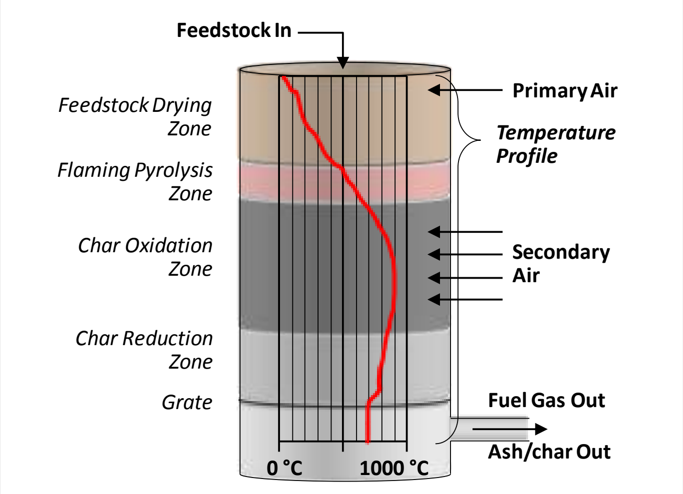


OFWEC III System

MEWEPS Gas Production Module at Camp Grayling

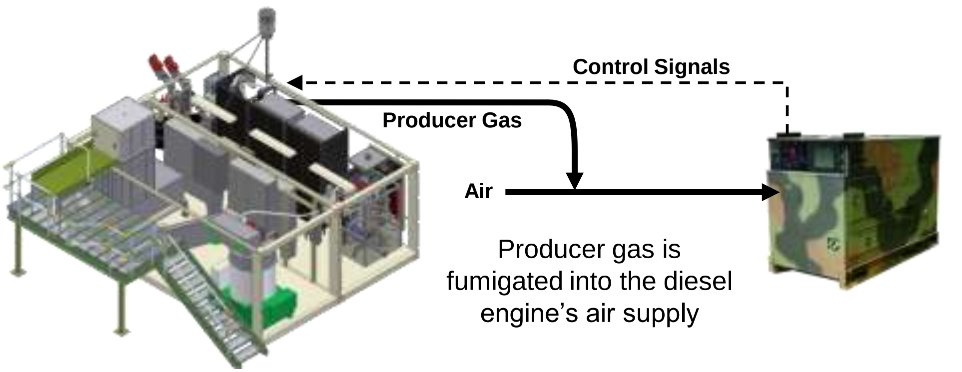
Community Power Corporation
(BioMax® Downdraft Gasifier)

BioMax® Gasifier Fundamentals



Zone	Description
Drying Zone	Feedstock is heated and dried, moisture released as steam
Pyrolysis Zone	Feedstock releases vapors which burn in the primary air and traverse downward
Oxidation Zone	Secondary air added for oxidation to produce carbon dioxide and heat
Reduction Zone	Hot char reacts with steam and carbon dioxide to form carbon monoxide and hydrogen

Bi-fuel Power Generation with Diesel Generator



- No modifications to 60kW Tactical Quiet Generator set
- Producer gas flow is adjusted in response to electrical load
- Up to 80% displacement of diesel fuel with producer gas

OFWEC III

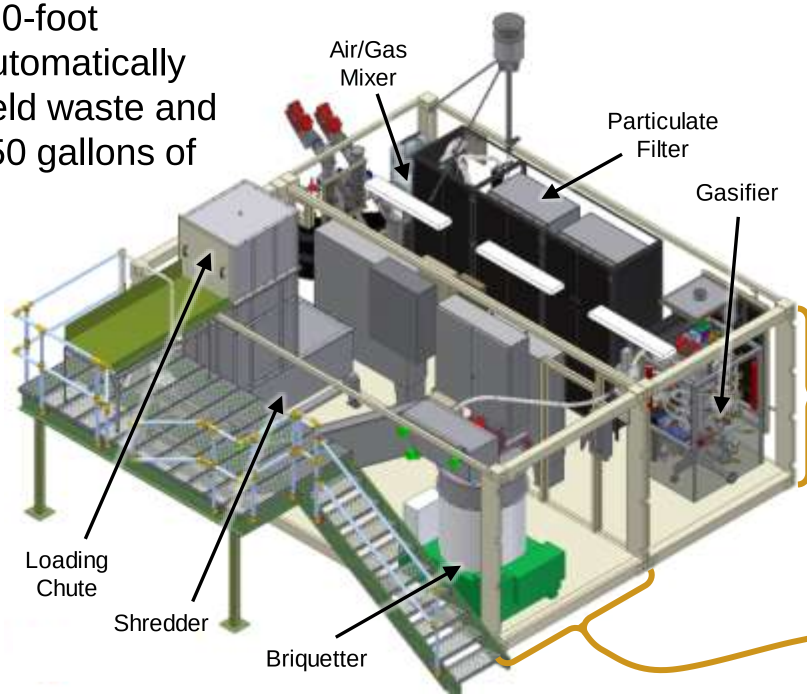
Onsite Field-feeding Waste to Energy Converter—Phase III

OFWEC III is a 3rd-generation prototype system that demonstrates technology that can be used to convert solid waste into useful energy. It has two logistical priorities: reduce the need for waste disposal, and reduce the need to transport fuel.

The core of the system is Community Power Corporation's BioMax® gasifier, which converts carbonaceous feedstock into a clean producer gas that is burned in a 60 kW Tactical Quiet Generator's internal combustion engine.

The system is packaged into two 20-foot containers for transportability. It automatically processes up to 1200 lb/day dry field waste and can export electricity worth over 250 gallons of diesel or JP-8 each week.

OFWEC III System Technology Demonstration at Fort Irwin, March 2011



Gas Production Module

Feedstock Conditioning Module

OFWEC III Demonstration
Net Zero Plus JCTD, Fort Irwin

Two-Week Technology Demonstration at Net Zero Plus JCTD

- Connected to EPCC microgrid
  - Supplied 50 kW power to Special Operations Task Force site
- Processed RUBA and field waste from the 1st Brigade Combat Team, 1st Cavalry Division (Iron Horse HBCT)
  - Plus garrison waste and wood pallets
- Preliminary performance data:
  - 41.3 lb/h processing rate (average)
  - 98% volume reduction and 93% weight reduction of feedstock
  - 1.4 gal/h net fuel savings after 8.4 kW parasitic power requirement
  - Throughput limited by briquetter with moist feedstock

HEDWEC
(ARL / NSRDEC Effort)

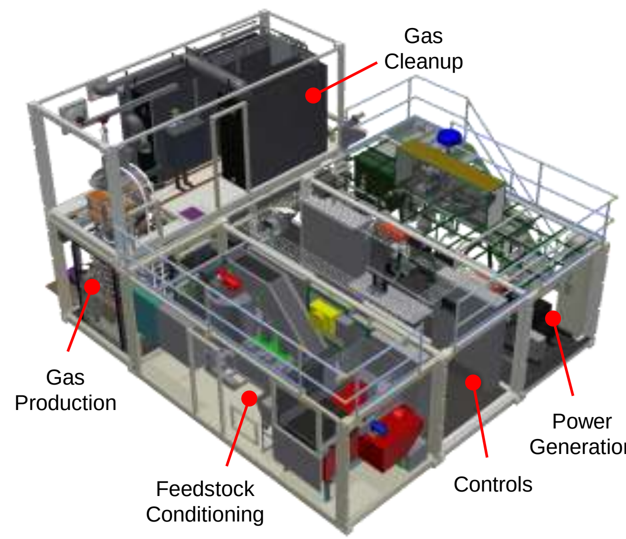
HEDWEC

High Energy Density
Waste to Energy Converter

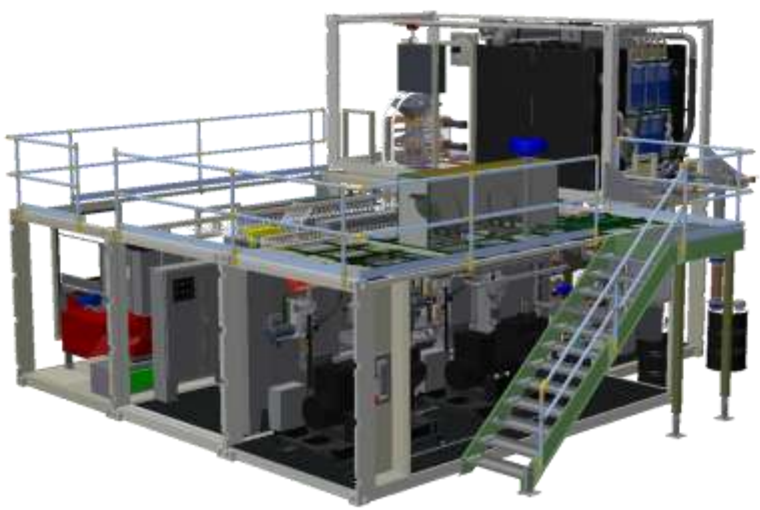
The HEDWEC effort is an FY08 Alternative Energy Research Increase managed by ARL and NSRDEC. The objective is to develop and demonstrate a battalion-scale system that converts trash into electricity and meets the CASCOM objective of processing 2 tons/day mixed waste as expressed in the Force Provider draft CPD.

HEDWEC incorporates a brand new 24"-diameter BioMax® gasifier that can process up to 200 lbs/hour. Wet food is added separately and dehydrated before being fed to the gasifier. Power is generated with a custom 120 kW gas generator system or multiple Army diesel gensets.

The prototype will be delivered in FY12 for government testing.



	OFWEC III	HEDWEC
Current Maturity	TRL 7	TRL 5
Tech Demo	Net Zero Plus (Mar 2011)	Hickam AFB (plan)
Feedstock	Primarily Dry Packaging	Foodservice Waste
Size	20-foot ISO x 2	20-foot ISO x 4
Capacity	0.6 ton/day	2-3 ton/day
Generator	60 kW TQG	120 kW custom (1x 20-foot ISO)
Cold Gas Efficiency	70-80%	70-80%
Electrical Efficiency	~16% (net)	TBD (similar)
Fuel Savings	200+ gal/week	500+ gal/week

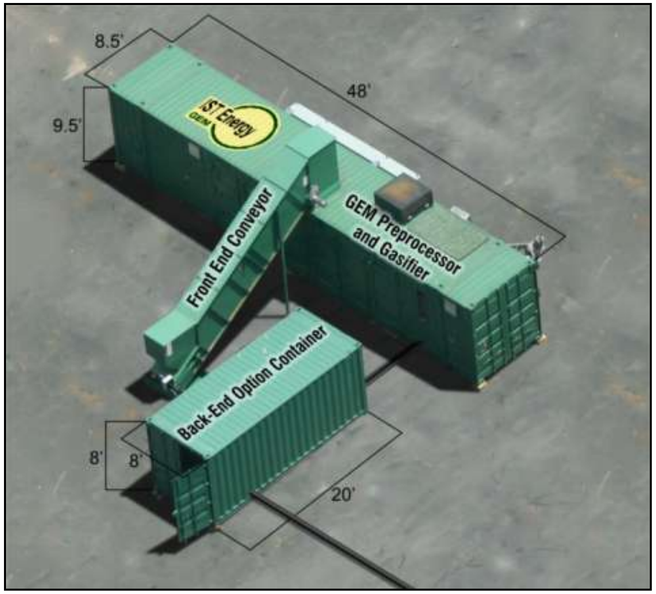


Infoscitex GEM
(Tracked ESTCP Effort)

GEM Green Energy Machine

The first GEM prototype was developed by Infoscitex Energy with private funding and the results of three SBIR/STTR contracts. Infoscitex subsequently received ESTCP funding for upgrades and long term demonstration of GEM at Edwards AFB in FY12.

The current GEM is designed for up to 3 TPD bulk mixed waste, including paper, wood, plastic, food and agricultural waste. The system uses a shredder, dryer, and pelletizing preprocessor to fuel an in-house developed downdraft gasifier. After filtration, the producer gas is used to power a 135 kW diesel generator. GEM is packaged in a 48-foot high cube container plus a 20-foot container for power generation and distribution.



	GEM (ESTCP version)
Current Maturity	TRL 6
Tech Demo	Edwards AFB (FY12)
Feedstock	Unsorted Mixed (<40% moisture)
Size	48-foot high cube
Capacity	2-3 ton/day
Generator	135 kW diesel (1x 20-foot ISO)
Cold Gas Efficiency	70-80%
Electrical Efficiency	~12% (net)
Fuel Savings	400-800 gal/week

QinetiQ PWDS
(Tracked PM-FSS FCT Effort)

PWDS Pyrolysis Waste Destruction System

PWDS is based on QinetiQ's Pyrolysis Total Energy Convertor system deployed on the amphibious assault ship, HMS Ocean.

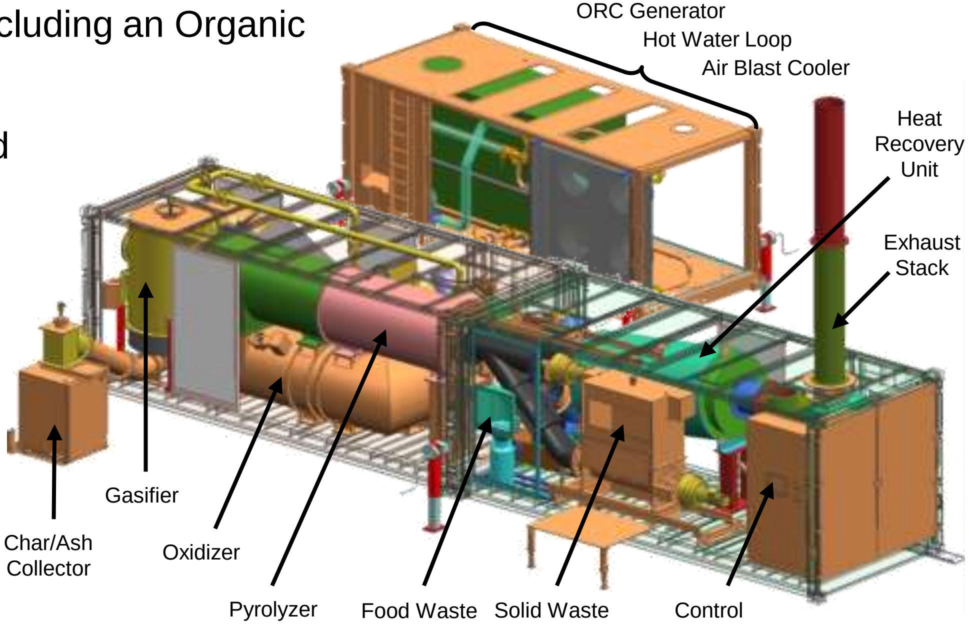
Under the Foreign Comparative Test program, PM Force Sustainment Systems evaluated PWDS for use with Force Provider. The reconfigured and containerized prototype was planned to undergo operational assessment at Fort Irwin and Aberdeen Test Center.

The pyrolysis system is packaged into two ISO containers, with a third container housing energy recovery subsystems including an Organic Rankine Cycle generator and hot water loop.

The system processes mixed waste, with food and sludge loaded separated from dry waste. An auger pulls feedstock through the system without pre-processing. Waste oil can also be processed. Maximum throughput is 220-250 lbs/hr, 2-3 TPD.

The system is more destructor than energy converter, but should be able to export more power than it consumes.

Testing ended early due to equipment failure and contractor performance issues.



Planned Accomplishments
FY11-12, by System

- OFWEC III
  - Technology demonstration with CERDEC gas-to-liquids system at Aberdeen Test Center ✔
  - Field demonstration in Net Zero Plus JCTD at Fort Irwin ✔
  - Demonstration at Base Camp SIL, Fort Devens
- HEDWEC
  - Complete development and fabrication
  - Demonstration/Validation at Hickam AFB
- GEM
  - ESTCP demonstration at Edwards AFB
- PWDS
  - Reliability testing at Fort Irwin ✘
  - User Assessment at Aberdeen Test Center ✘

Waste to Energy Conversion at NSRDEC

Where we're going…

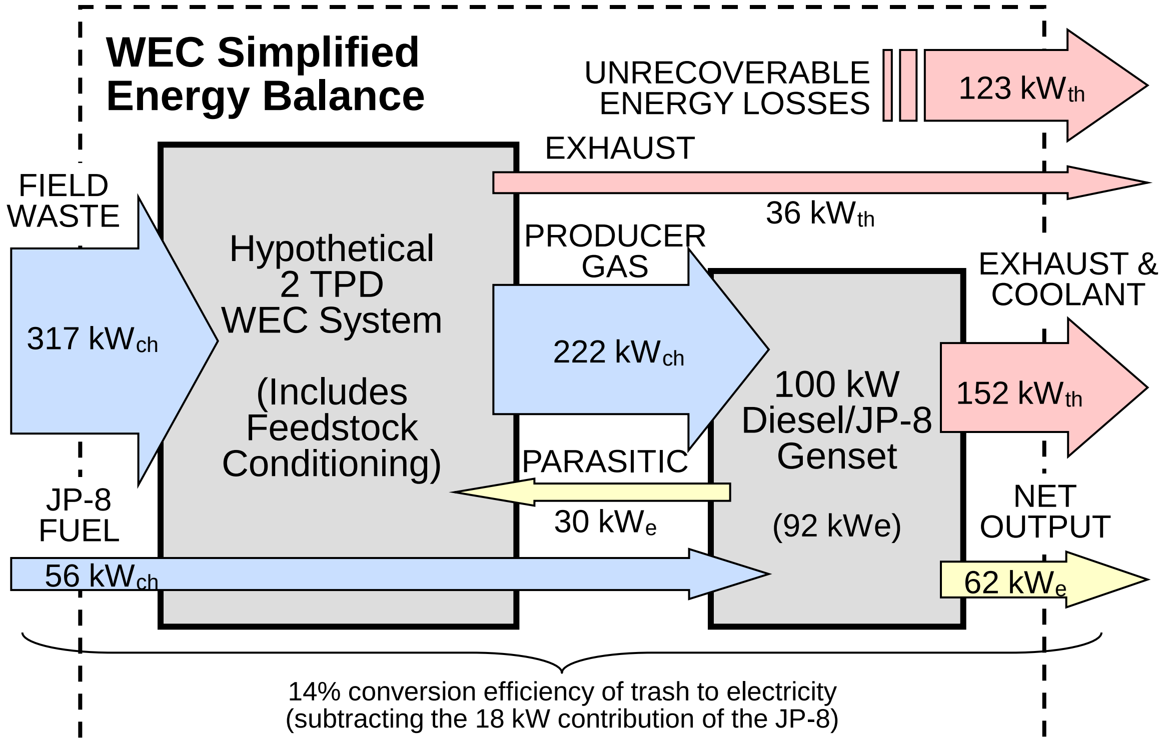
Energy Balance
Hypothetical 2TPD WEC System

Field Waste
Mixed base camp waste including foodservice, packaging, wood, textiles, etc.
167 lb/h
6500 BTU/lb HHV
~35% moisture

Gasifier requires 10% moisture

Producer Gas
Clean, low-tar, low-BTU flammable gas; diluted with N_2, water vapor, and CO_2; ~70% eff.

Parasitics
Electrical power required for startup, shredding, drying, blowers, augers, etc.



Using diesel generator, 1.5 gal/h fuel is invested to export electricity worth 5.1 gal/h (3.4x ROI)

Efficiency
Trash to electricity efficiency subtracts the value of the pilot fuel, assuming it otherwise would have been used to generate electricity at full efficiency

Performance Metrics
Converts 317 kW trash to 44 kWe net (13.7% eff.)
Electrical Output: 520 kWhe/ton or 1040 kWhe/day
Fuel Displaced: 3.6 gal/h, 87 gal/day, or 521 gal/week (24x6)

Losses
Char residuals, evaporation, heat losses

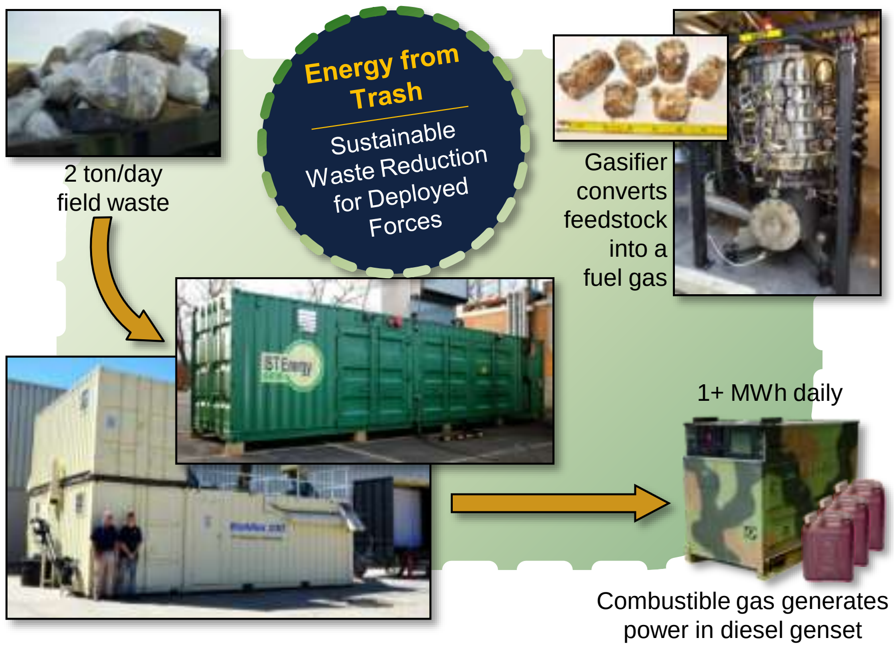
Heat
Exhaust heat may be useful for drying feedstock, space and/or water heating

Generator
Diesel generator runs on mixture of JP-8 and producer gas, assuming 33% efficiency (more data needed)

Fuel
JP-8 (or diesel) required as pilot fuel for genset; this analysis assumes 80% diversion

Waste Disposal with Energy Conversion

FY11 Alternative Energy Research Increase



Schedule & Funding

Milestones	FY11	FY12	FY13	FY14
Devens SIL Testing (OFWEC)	6	7		
HEDWEC Upgrades				
Hickam AFB Demo (HEDWEC)		7		
2 TPD WEC Pre-Solicitation				
2 TPD WEC Phase I		5		
2 TPD WEC Phase II				6
Demonstrations				7
Technology Transition				
TOTAL $				

Purpose:

- Provide capability to minimize contingency basing solid waste while exporting electricity
  - Paradigm shift: Waste is less a liability, more an energy resource
- Reduce logistics and improve safety for the Warfighter
- Address challenges from previous prototypes to provide a robust and transitionable final product

Results/Products:

- Technology demonstration of WEC suitable for Force Provider, large Combat Outposts, and/or small Forward Operating Bases
  - Processes 2 TPD mixed non-hazardous solid waste
  - Packaged in 20’ ISO containers for deployability
  - Includes power generation for net energy export
  - Automatic control and operation, minimal manpower
  - Benign residuals and emissions

ROI/Payoff:

- Reduce logistic burden of contingency basing
  - Reduce two costly burdens: waste & fuel
  - “Trucks off the road” = force protection
- Transition to PM-FSS in FY14
- Addresses WFOs: 3, 30, 47, 65, 71

Performance Barriers
Battalion-scale WEC

- WEC technologies are being demonstrated feasible, but several performance barriers remain:
  - Too Large / Heavy
  - Too Inefficient (poor ROI)
  - Too Expensive
  - Limited Feedstock
- Successfully addressing these challenges should result in systems suitable for widespread deployment
- No major breakthroughs expected without Government investment
  - Comparatively little demand in the commercial sector
  - ROI highest where the fully burdened cost of fuel or waste is high
- Army R&D should focus on approaches that address the greatest deficiencies of current systems

Perceived Requirements for Force Provider WEC

System	**Complete system** ingests bagged solid waste and exports electricity
Force Size	Battalion level (**600**)
Feedstock	**Mixed non-hazardous solid waste** (from foodservice and other activities, with variable constituents and moisture content) Desired: All solid waste, including pallets, motor pool, medical
Throughput	**2 tons per day**, accounting for maintenance and availability
Emissions	Regulatory compliance and **no smoke or odor signature** for operation within the camp
Residues	**Non-hazardous** residuals (char/ash)
Packaging	Not more than **3x 20-foot ISO containers** (all components, including feedstock conditioning and power generation)
Manpower	**Minimal labor** (manual waste segregation highly undesirable)
Efficiency	**Net zero minimum**, system self-sufficient without adding fuel or power
Cost	**Less than $1M**, but commensurate with ROI

Closing Remarks
Maximizing ROI

- **WEC fuel savings will be small compared to today's fuel demand from a Force Provider supported camp**
  - WEC should be considered one piece of a holistic approach to reduce the logistic bootprint of deployed forces

- **WEC benefits can be maximized by using it smartly**
  - Connect to a micro-grid to ensure demand for all electrical power produced while also providing surge capacity for power hungry subsystems (such as shredders)
  - Operate as a combined heat and power device, using the "waste" heat for space or water heating
- **WEC cost savings will always be most substantial where the fully burdened cost of fuel and/or waste disposal is high**

Army Net Zero Initiative and Waste to Energy (WTE) Opportunities

Mr. FRANKLIN H. HOLCOMB

Chief, Energy Branch

U.S. Army ERDC-CERL

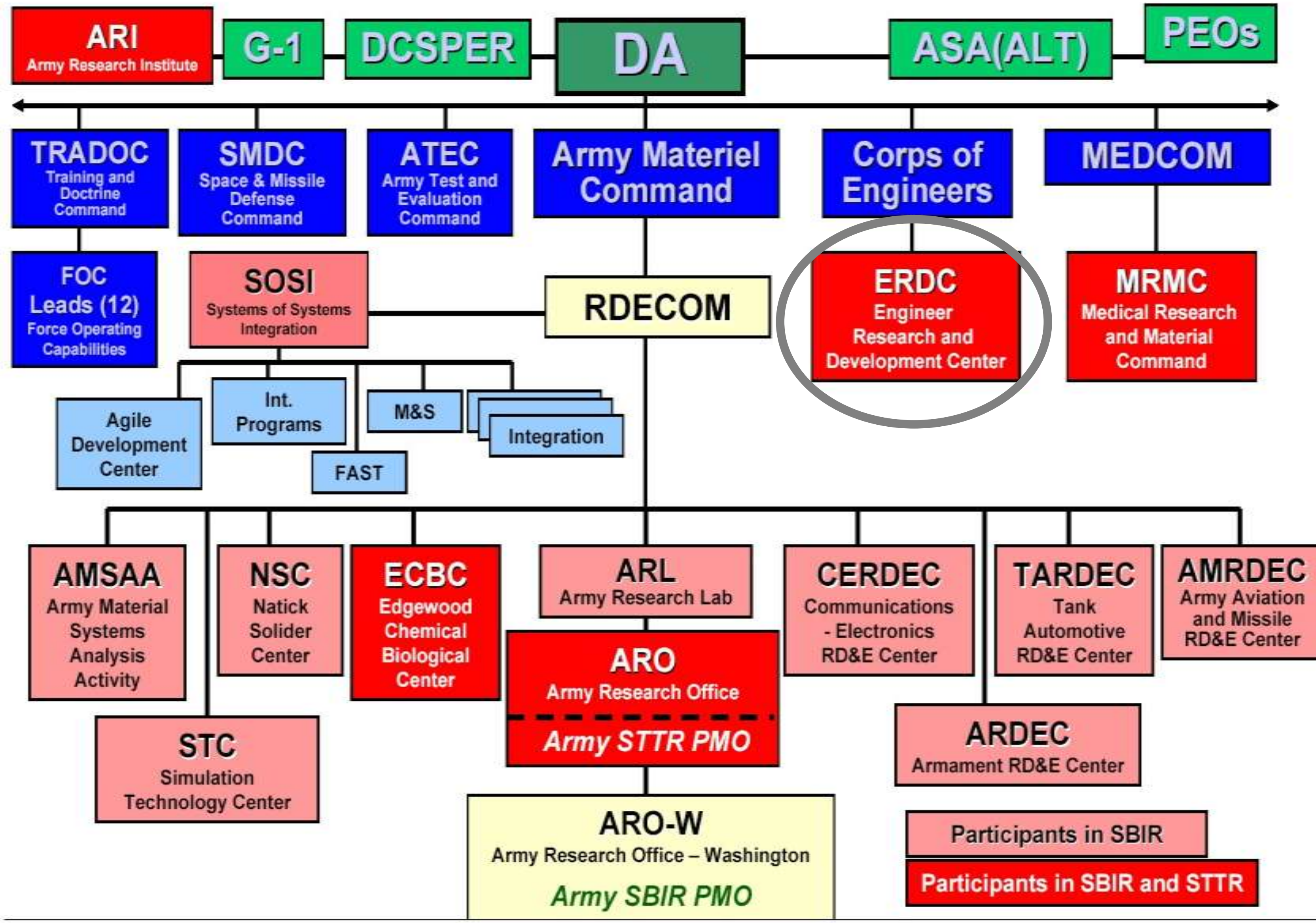
Champaign IL USA

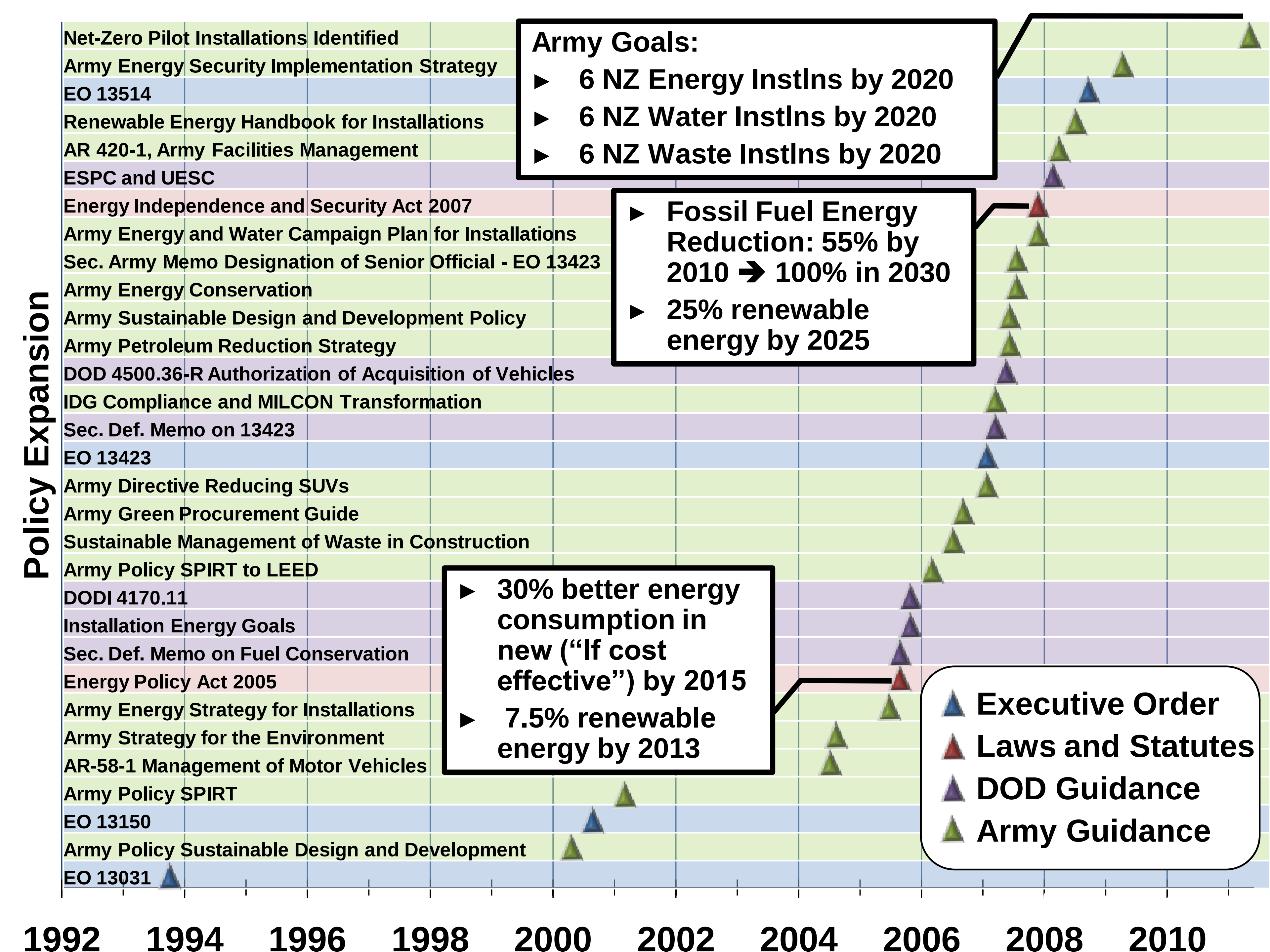
28 September 2011

US Army Corps of Engineers
BUILDING STRONG®

Distribution Statement A - Approved for public release; distribution is unlimited.

ARMY R&D Organizations




Policy Expansion
Net-Zero Pilot Installations Identified
Army Energy Security Implementation Strategy
EO 13514
Renewable Energy Handbook for Installations
AR 420-1, Army Facilities Management
ESPC and UESC
Energy Independence and Security Act 2007
Army Energy and Water Campaign Plan for Installations
Sec. Army Memo Designation of Senior Official - EO 13423
Army Energy Conservation
Army Sustainable Design and Development Policy
Army Petroleum Reduction Strategy
DOD 4500.36-R Authorization of Acquisition of Vehicles
IDG Compliance and MILCON Transformation
Sec. Def. Memo on 13423
EO 13423
Army Directive Reducing SUVs
Army Green Procurement Guide
Sustainable Management of Waste in Construction
Army Policy SPIRT to LEED
DODI 4170.11
Installation Energy Goals
Sec. Def. Memo on Fuel Conservation
Energy Policy Act 2005
Army Energy Strategy for Installations
Army Strategy for the Environment
AR-58-1 Management of Motor Vehicles
Army Policy SPIRT
EO 13150
Army Policy Sustainable Design and Development
EO 13031
Army Goals:
► 6 NZ Energy Instlns by 2020
► 6 NZ Water Instlns by 2020
► 6 NZ Waste Instlns by 2020
► Fossil Fuel Energy Reduction: 55% by 2010 ➔ 100% in 2030
► 25% renewable energy by 2025
► 30% better energy consumption in new (“If cost effective”) by 2015
► 7.5% renewable energy by 2013
Executive Order
Laws and Statutes
DOD Guidance
Army Guidance
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010

Net Zero Hierarchy

- **A Net Zero ENERGY Installation** produces as much energy on site as it uses, over the course of a year.
- **A Net Zero WATER Installation** limits the consumption of freshwater resources and returns water back to the same watershed so not to deplete the groundwater and surface water resources of that region in quantity or quality.
- **A Net Zero WASTE Installation** reduces, reuses, and recovers waste streams, converting them to resource values with zero landfill over the course of a year.

A Net ZERO INSTALLATION applies an integrated approach to management of energy, water, and waste to capture and commercialize the resource value and/or enhance the ecological productivity of land, water, and air.

Net Zero Pilot Installations

18 sites announced - 19 April 2011

NET ZERO ENERGY PILOT SITES:
Fort Detrick, MD
Fort Hunter Liggett, CA
Kwajalein Atoll, Republic of the Marshall Islands
Parks Reserve Forces Training Area, CA
Sierra Army Depot, CA
West Point, NY

NET ZERO WATER PILOT SITES:
Aberdeen Proving Ground, MD
Camp Rilea, OR
Fort Buchanan, PR
Fort Riley, KS
Joint Base Lewis-McChord WA
Tobyhanna Army Depot, PA

NET ZERO WASTE PILOT SITES:
Fort Detrick, MD
Fort Hood, TX
Fort Hunter Liggett, CA
Fort Polk, LA
Joint Base Lewis-McChord WA
U.S. Army Garrison, Grafenwoehr, Germany

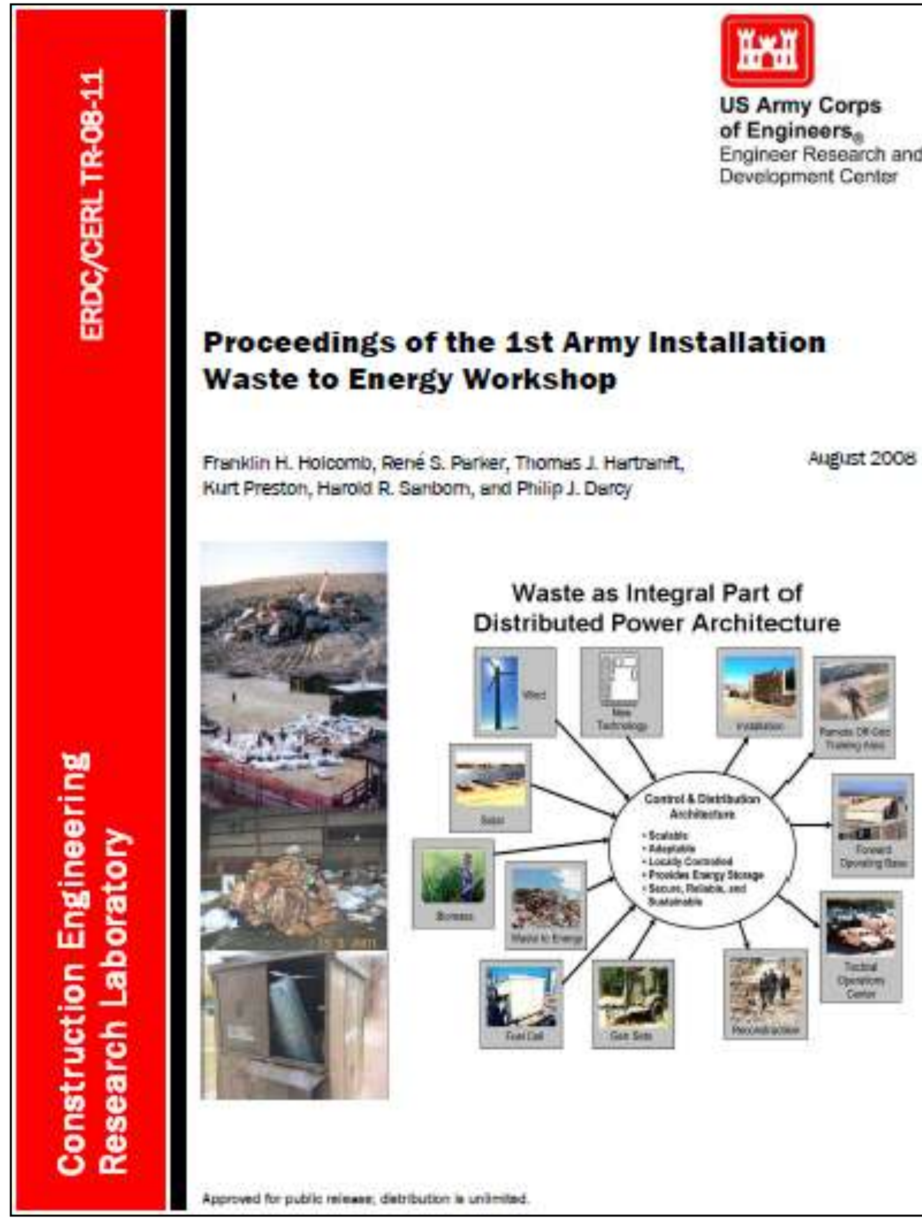
NET ZERO OVER-ALL PILOT SITES:
Fort Bliss, TX
Fort Carson, CO

STATE-WIDE ENERGY INITIATIVE:
Oregon Army National Guard

The Army is piloting six installations to be Net Zero Energy, six installations to be Net Zero Waste, six installations to be Net Zero Water, and two installations to be all three by 2020. The Army goal is to have 25 Net Zero Installations by 2030.

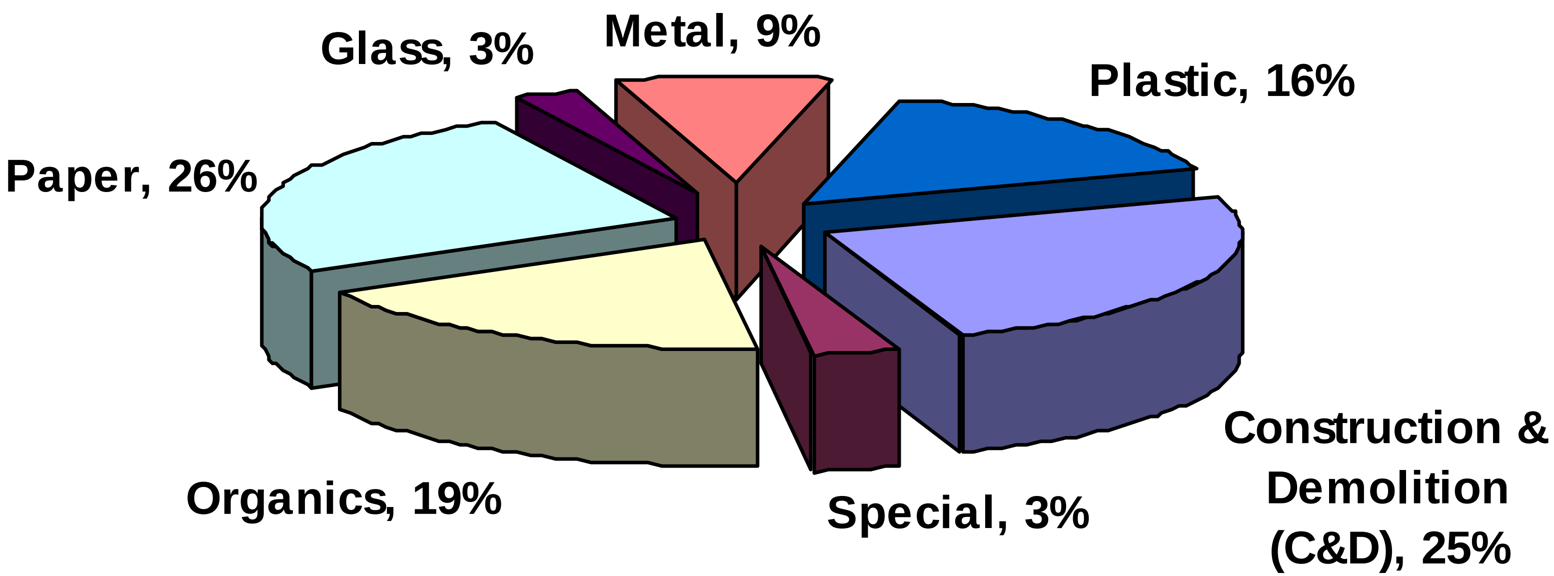
1st Installation WTE Workshop held at Army Research Office in May 2008

- Goals were to share information, spread visibility on current efforts, and explore the potential of waste to energy technologies for Army (and DoD) installations, and to potentially launch working groups to further advance implementing installation waste to energy technologies.
- Identified a Need to Determine the "Burdened" Cost of Waste at Installations
- 2nd Workshop Sponsored by Air Force on 22-23 JAN 2009 (Alt Energy Now!)



http://dodfuelcell.cecer.army.mil/library_items/ERDC-CERL_TR-08-11.pdf

Solid Waste Composition
Example Army Installation



Technology Survey

- Combustion Processes (~ 30 tons waste/day = 1 MW)
  - Least costly to build, O&M costs higher then gasification(?)
  - Many plants operating, but bad reputation
  - Combustion produces CO2 and ash, potentially hazardous waste ash
  - Cooling water can limit locations

- Gasification (syngas) Processes (~20 tons waste/day = 1 MW)
  - Limited plants operating, but mostly well received
  - Plant produces syngas, generator produces power
  - Syngas can be piped elsewhere, along with some of CO2 liability
  - Water use varies by plant design

- Prices vary widely from 5-6 cents/kWh to 9-10 cents/kWh, depending on scale, plant type, etc.

Solid Waste Issues

- Operational And Maintenance Burdens
- Tipping, Transportation, And Contractor Costs
- Regulatory and Other Compliance Issues
- Safety and Health Issues
- Natural Infrastructure Demands
- Greenhouse Gas Emissions
- Operational Security (OPSEC) Concerns

Waste = Liability

Challenges with Waste to Energy

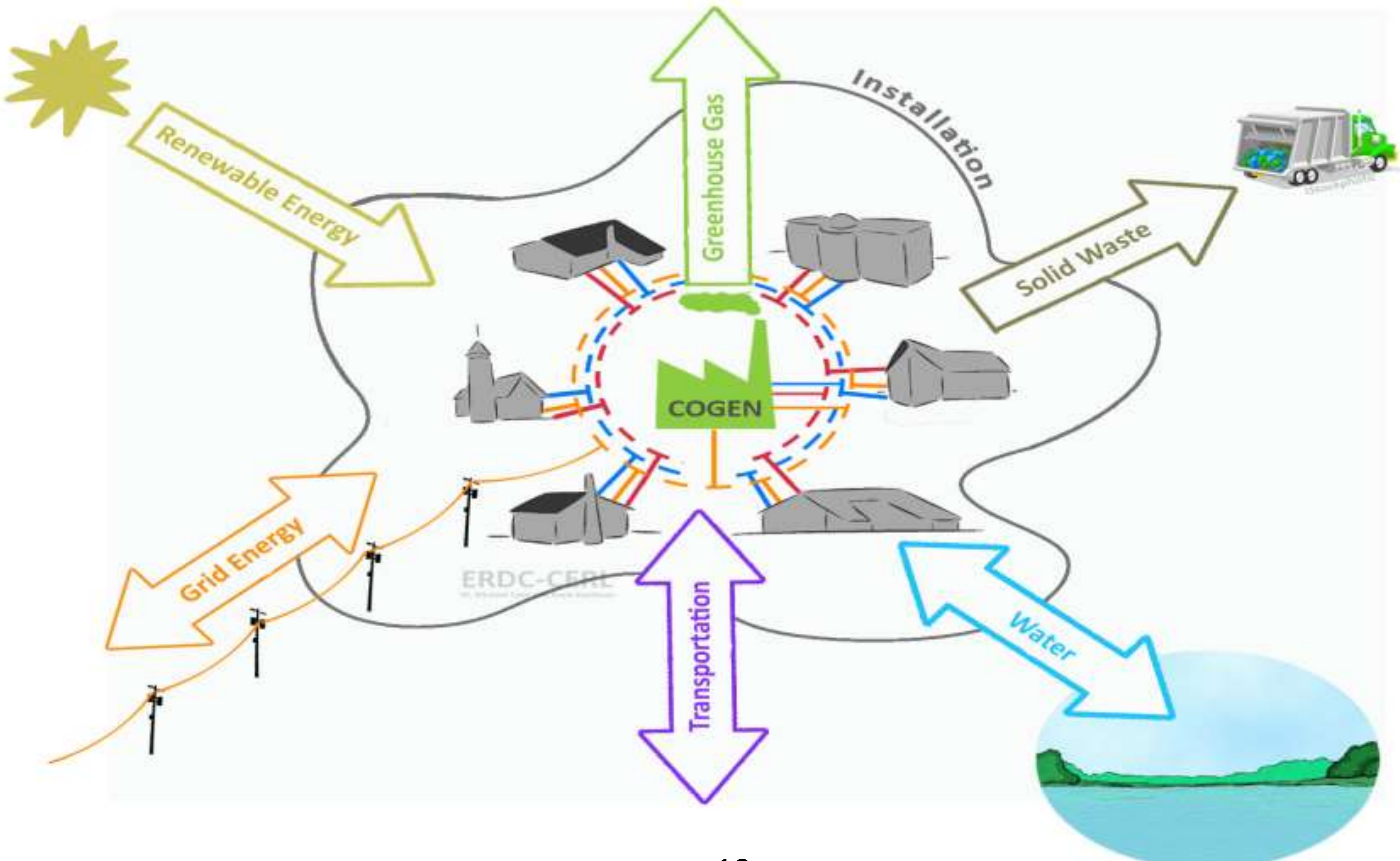
- Feedstock handling/pre-processing/transportation
- Feedstock (moisture content, characterization, quantity/consistency)
- Technology scale-up/down
- Producer/Syngas gas cleanup
- By-product (ash/char) handling and disposal
- Public perception
- Dispatch of electricity (siting plant near distribution lines, interconnect issues)
- Financing
- Privatization

Conclusions – WTE Projects at Army Installations

- Net Zero goals → Reduce/Reuse/Recover
- Need to Determine the “Burdened” cost of Waste
- 3rd Party Financing Required for WTE Projects
- Privatization of Utilities is an Issue
- Siting & Permitting can be an Issue

*WTE Systems for Tactical Operations have different requirements!

Backup Slide - 6.2 R&D Project
Energy, Water, and Waste Integrated Model - EW2



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St. Kitts Energy Project

Home of the Green Vervet Monkey

Aliyah Pandolfi

Al-Kareem Foundation

St. Kitts Background

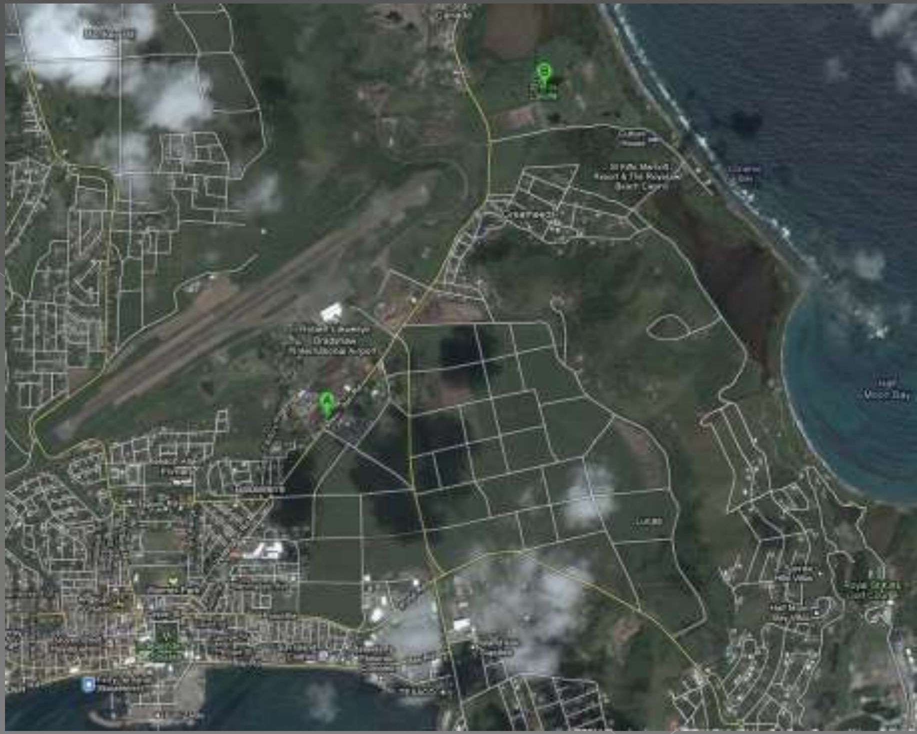
- Freedom from England: 1983
- Population: 50,000
- Literacy Rate: 97.8%
- Main Industry until 2005: Sugar
- Main industry currently: Tourism
- Total Area: 41,600 Acres (65 mile^2)
- Arable Land: 7,900 Acres (12 mile^2)

St. Kitts Waste

Total waste: 155 tons/day

6.2 lbs/person

- Commercial Garbage: 60 tons/day
- Scrap Metal: Buried
- Tires: Burned
- Everything else: Burned or buried



Point A: Needsmust Power Station
Point B: St. Kitts Landfill
Distance ~ 1 mile

St. Kitts Electrical Power Plant

Old Plant

- Opened in 1971
- Electricity capacity: 35 MW
- Fuel: Imported diesel

Extension to old plant

- Opened in 2011
- Electricity capacity: 8 MW
- Fuel: Imported diesel
- Cost: $22 Million

Fuel Consumption: ~720 barrels/day ($62K/day @ $2/gallon)

St. Kitts Electricity Cost

Residential Consumer cost before 01/01/2011		
KW Hours	EC$	US $
50 Units	.32	.12
51-125	.35	.13
125+	.37	.14

Residential Consumer cost after 01/01/2011*			
KW Hours	EC $	US $	% Increase
50 Units	.59	.22	84%
51-150	.65	.24	86%
151+	.68	.25	84%

Commercial Consumer cost before 01/01/2011		
KW Hours	EC$	US $
50 Units	.50	.19
51-125	.43	.16
126-225	.37	.14
225+	.28	.10

Commercial Consumer cost after 01/01/2011**			
KW Hours	EC $	US $	% Increase
50 Units	.80	.30	60%
51-125	.76	.28	78%
126-225	.72	.27	96%
225+	.65	.24	132%

*Demand charge = $13 for fuse protecting services
**Demand charge = $15 per kva
Addition fees for fuel surcharge change based on monthly fuel costs.

St. Kitts Energy Project

- Eliminate daily waste
- Mine existing waste
- Eliminate process waste from cruise ships
- Produce fuel for electrical power generators
- Produce building material
- Provide jobs
- Tourist attraction
- Reduce electricity costs

Contact Information

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St. Kitts Energy Project Director

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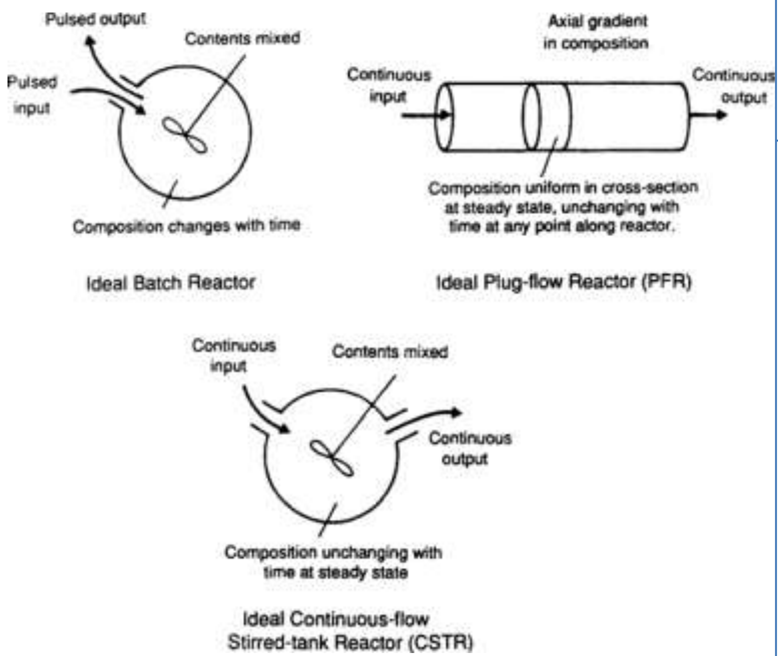
Perspectives on Plasma Gasification for Waste Processing and Energy Consumption

Prof. Ronald S. Besser
Chemical Engineering and Materials Science
Stevens Institute of Technology
Hoboken, NJ

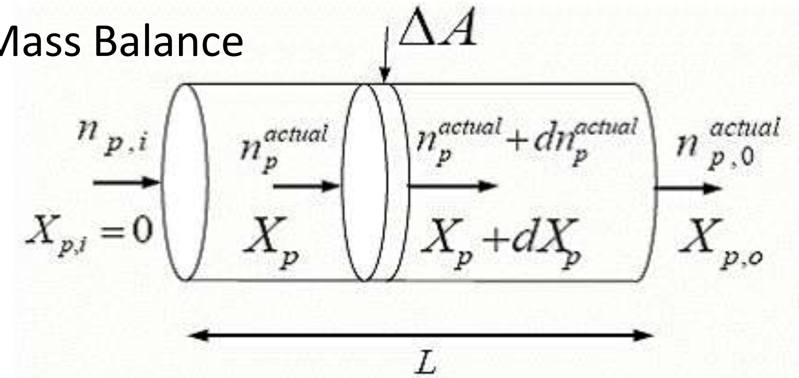
STEVENS INSTITUTE of TECHNOLOGY

Perspective: Chemical Reaction Engineering / Chemical Reactor Design and Analysis



Ideal Reactor Types

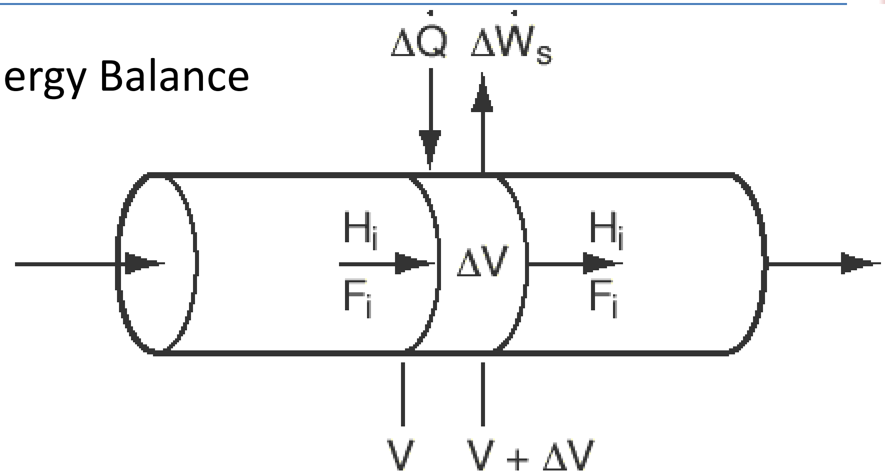
Mass Balance



$$\begin{pmatrix}\text{mass accu-}\\ \text{mulation}\\ \text{rate}\end{pmatrix} = \begin{pmatrix}\text{mass flux}\\ \text{in}\end{pmatrix} - \begin{pmatrix}\text{mass flux}\\ \text{out}\end{pmatrix} + \begin{pmatrix}\text{net rate of}\\ \text{chemical}\\ \text{production}\end{pmatrix} \quad \text{or,}$$

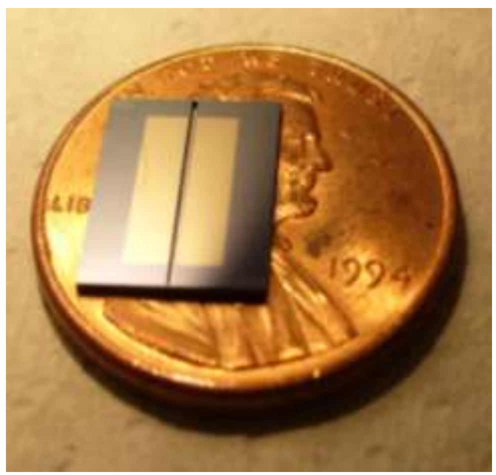
$$\frac{dm}{dt} = \dot{m}_{in} - \dot{m}_{out} + \dot{m}_{reaction} \tag{14}$$

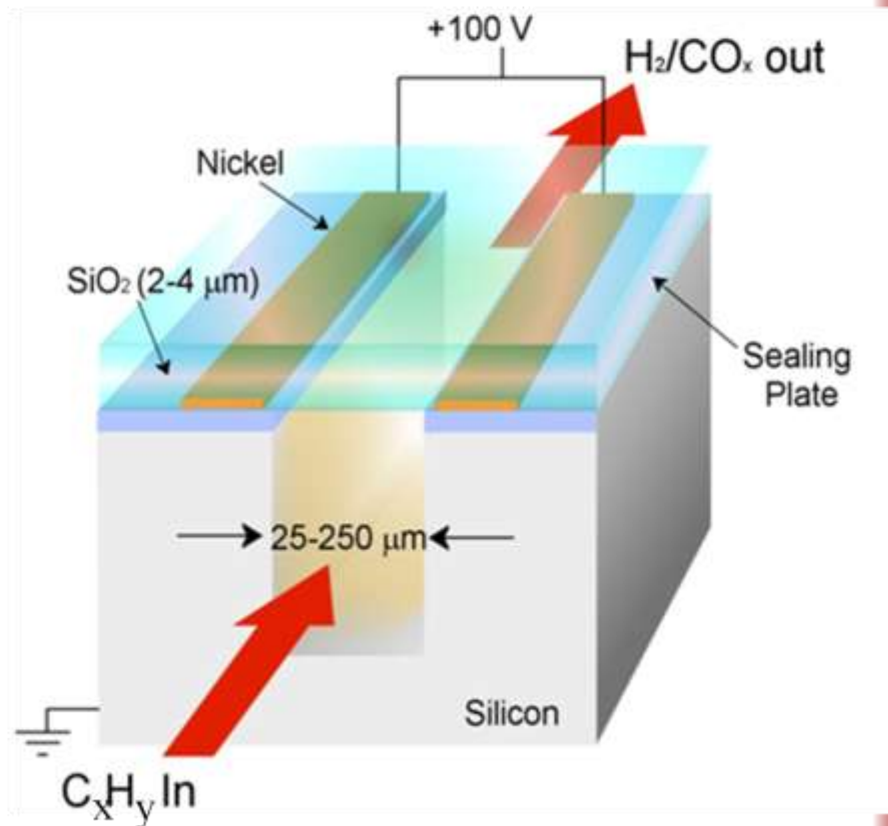
Energy Balance



$$\frac{dT}{dV} = \frac{Ua(T_a - T) + (-r_A)[-\Delta H_{Rx}(T)]}{F_{A0}(\Sigma\Theta_i F_i C_{pi} + X\,\Delta C_p)}$$

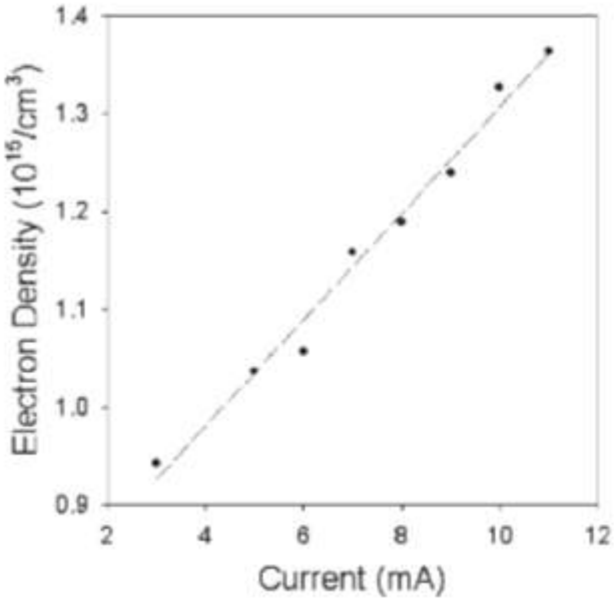
Perspective: Microplasma Reforming for Scalable Reforming of Hydrocarbons



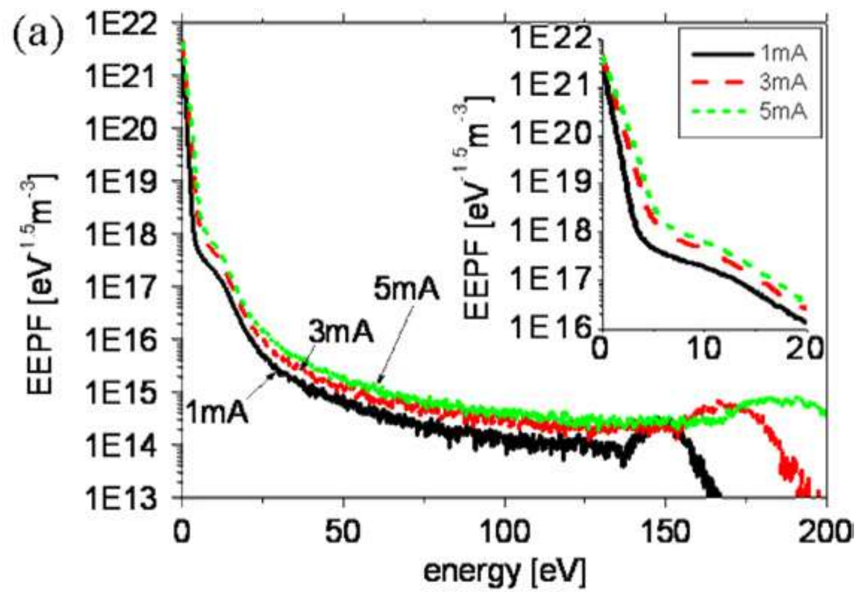


Funding:
Dr. Rob Mantz
ARO

Microplasma Reforming-New



MHCD, 220V DC, 760 torr Ar, 250 μm depth, 130 μm dia., KH Schoenbach, et. al., 2007



MHCD, 200 μm depth, 100 μm dia., 300 torr, Ar; GJ Kim, et. al., 2006

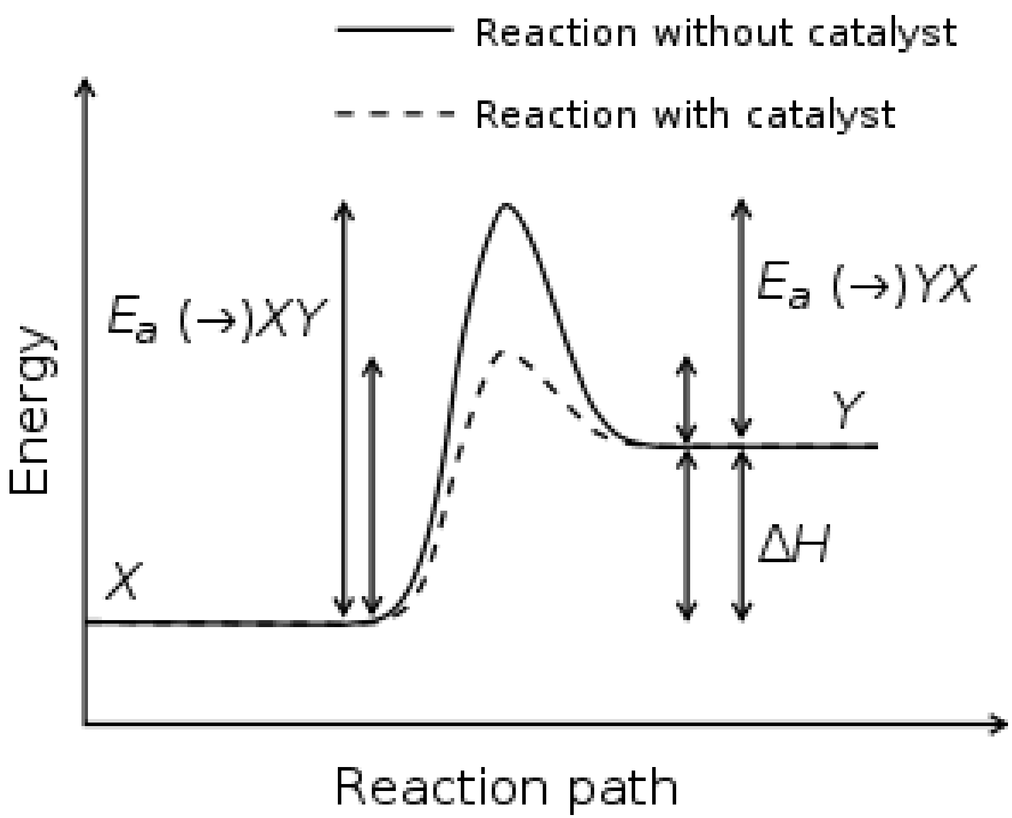
H-CH_2-CH_2-

Hydrogen bond energy ≈ 3 – 4 eV

[Electron Temperature ≈ 25,000 K !]

2. Background

Catalytic vs Microplasma Reforming Reactions



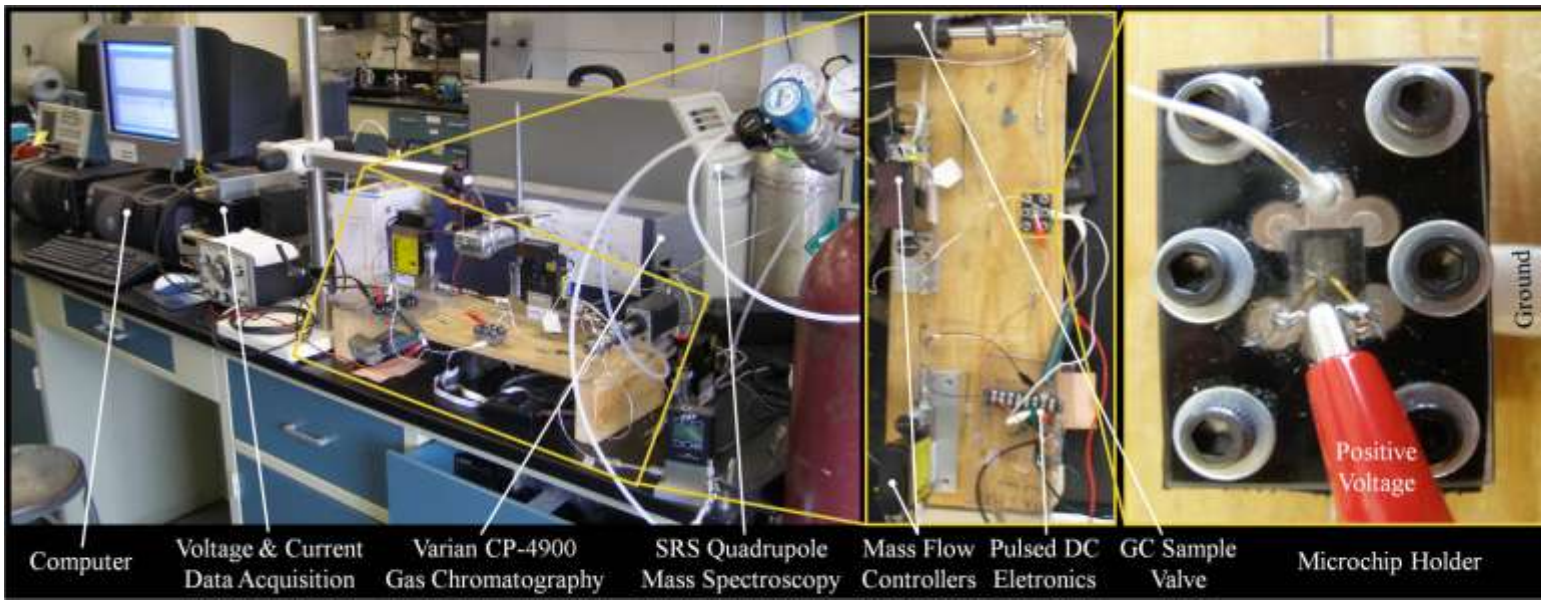
http://en.wikipedia.org/wiki/Activation_energy

Benefits of Microplasma Reaction Environment:

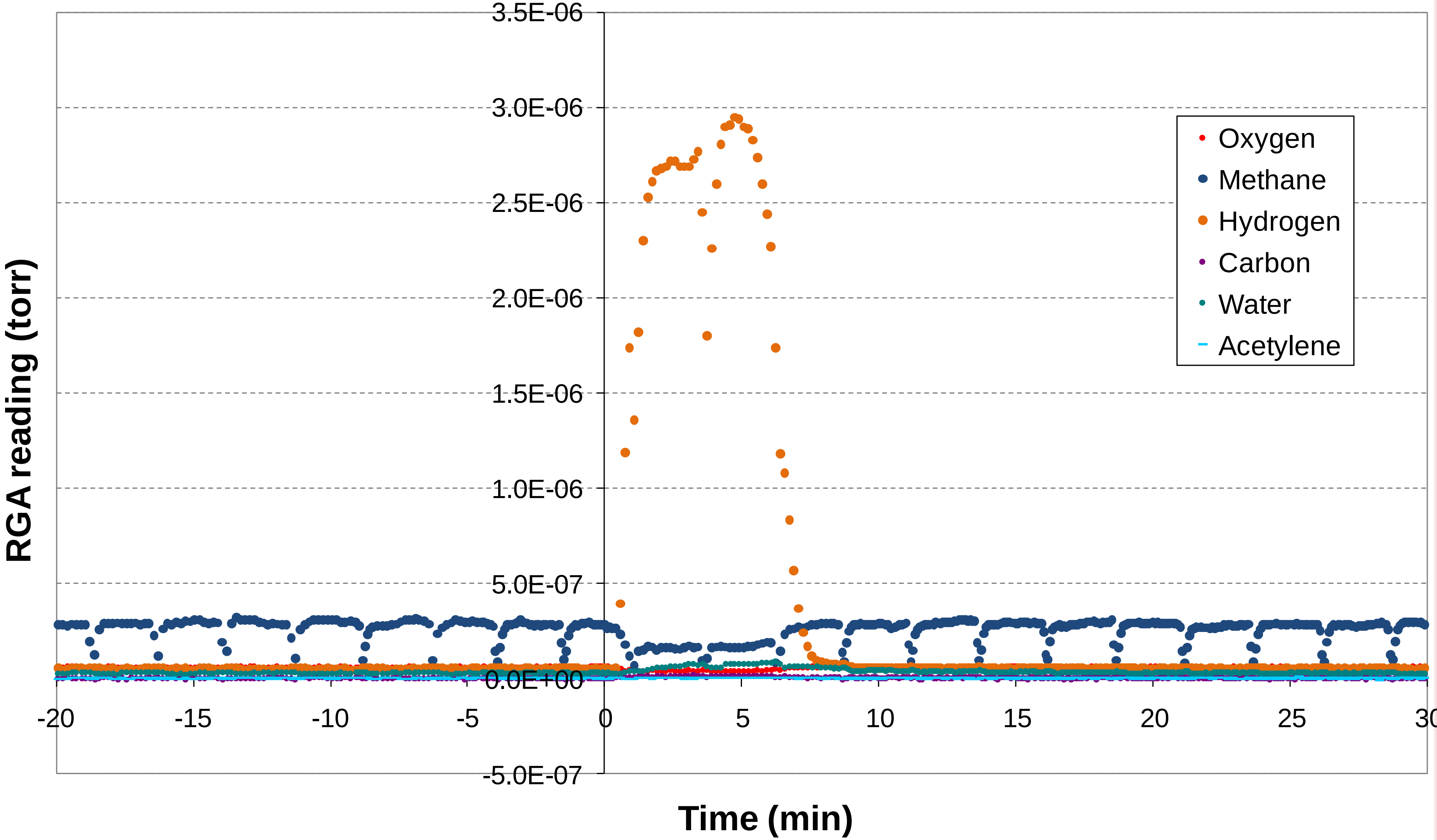
- No catalytic degradation such as coking or catalyst coarsening over time.
- Rapid start up.
- Operation at ambient temperature (reactor material compatibility issues significantly reduced).
- Operation at atmospheric pressure (more energy efficient for microplasmas due to lower breakdown voltages).
- **High electron density ~10^{15} cm^{-3} to facilitate chemical conversion of hydrocarbons.**

DC Power Supply

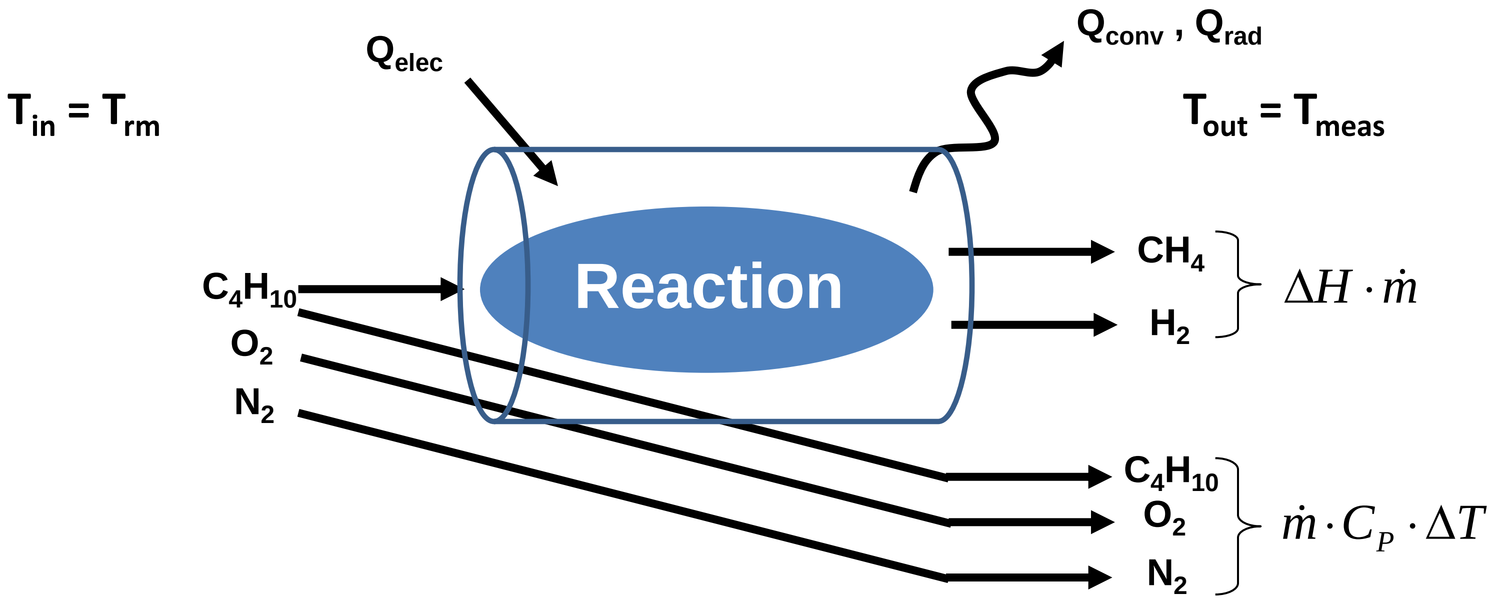
Pulsed DC Power Supply
10-50 kHz



Reactants and Products

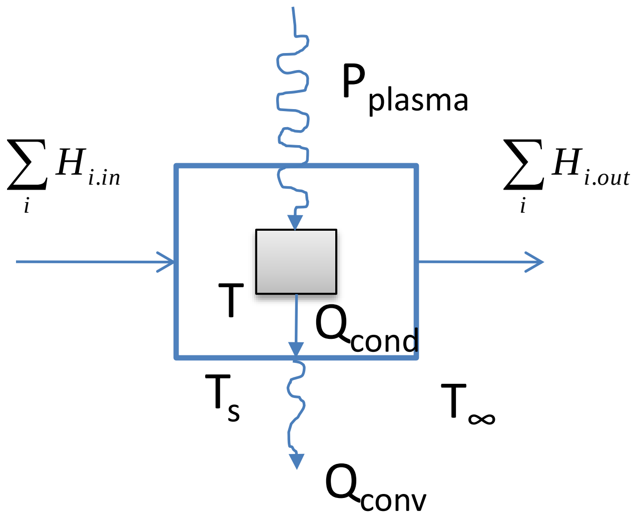


Mass and Energy Balances



$$\left(\sum_i H_i^0 \cdot \dot{m}_i\right)_{in} - \left(\sum_j H_j^{T_{out}} \cdot \dot{m}_j\right)_{out} + I \cdot V - \dot{Q}_{conv} - \dot{Q}_{rad} = \frac{d}{dt}\left(mC_pT\right)_{sys}$$

Energy Balance Approach



Assume ΔH << P_{plasma}, Q

$$\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{sys}}{dt} \neq 0$$

$$\boxed{P_{plasma} + Q = \left(mC_p\right)_{sys} \frac{dT}{dt}}$$

$$Q = Q_{cond} = Q_{conv}$$

$$kA\frac{T - T_s}{\Delta x} = hA\left(T_s - T_\infty\right)$$

With no plasma, gases still flowing:

$$Q = \left(mC_p\right)_{sys} \frac{dT}{dt}$$

$$Q = Q(T)$$

Outline

- Perspective: Chemical Engineering Reaction Engineering
- Perspective: Microplasma Reforming Research
- Energy Input: Feedstock Heating Values
- Biomass Conversion: Main Approaches
- Focus on Thermochemical Approach: Gasification
- Plasma Gasification Mechanisms
- Status: Modeling and Simulation
- Status: Process Scaling

Heating Values of Biomass Feeds

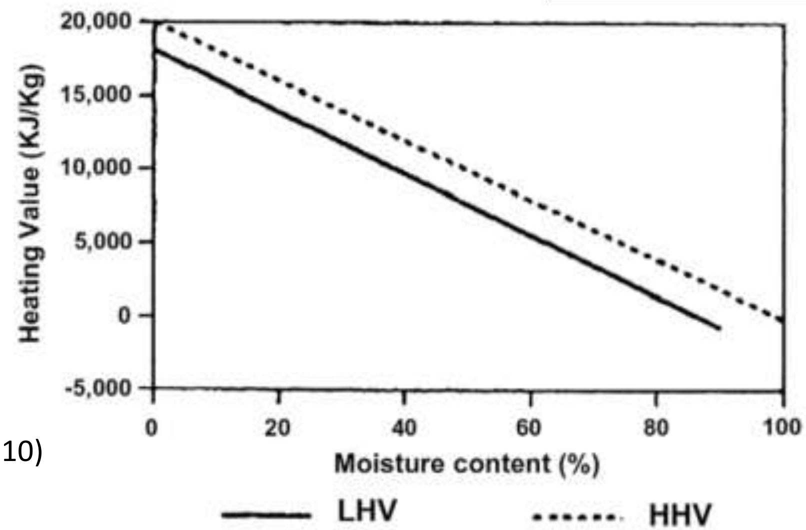
Biomass	Residue yield ($t\,ha^{-1}$)	Heating value ($MJ\,dry\,kg^{-1}$)
Wheat straw	2.97	17.9
Rice straw	4.52	16.8
Almond branches	6.21	18.4
Olive kernels	64.0	18.9
Ptolemais lignite	–	16.9
Forest residue	–	19.5
Hazelnut shell	–	15.43
Safflower seeds	–	23.86
Rapeseed	–	26.7
Cotton seed residue	–	16.9

(Saxena, 2009)

RDF composition and properties.

Proximate analysis (wt.%)		
Moisture	20	
Volatile matters (dry basis)	75.95	
Fixed carbon (dry basis)	10.23	
Ash (dry basis)	13.81	
Ultimate analysis (wt.%)		
C	48.23	
H	6.37	
N	1.22	
Cl	1.13	
S	0.76	
O	28.48	
Ash	13.81	
Heating values		
	Dry	20% Moisture
HHV (MJ/kg)	17.8	14.2
LHV (MJ/kg)	16.3	12.9

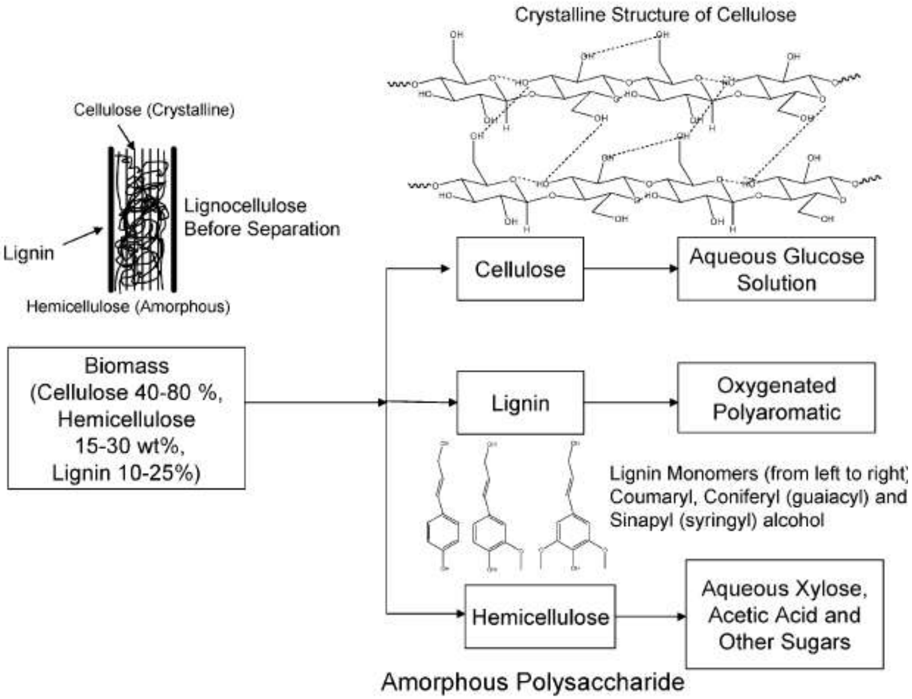
(Minutillo, 2009)



(Zhang, 2010)

Moisture Content is an Issue

Nature of Ligno-Cellulosic Feedstocks

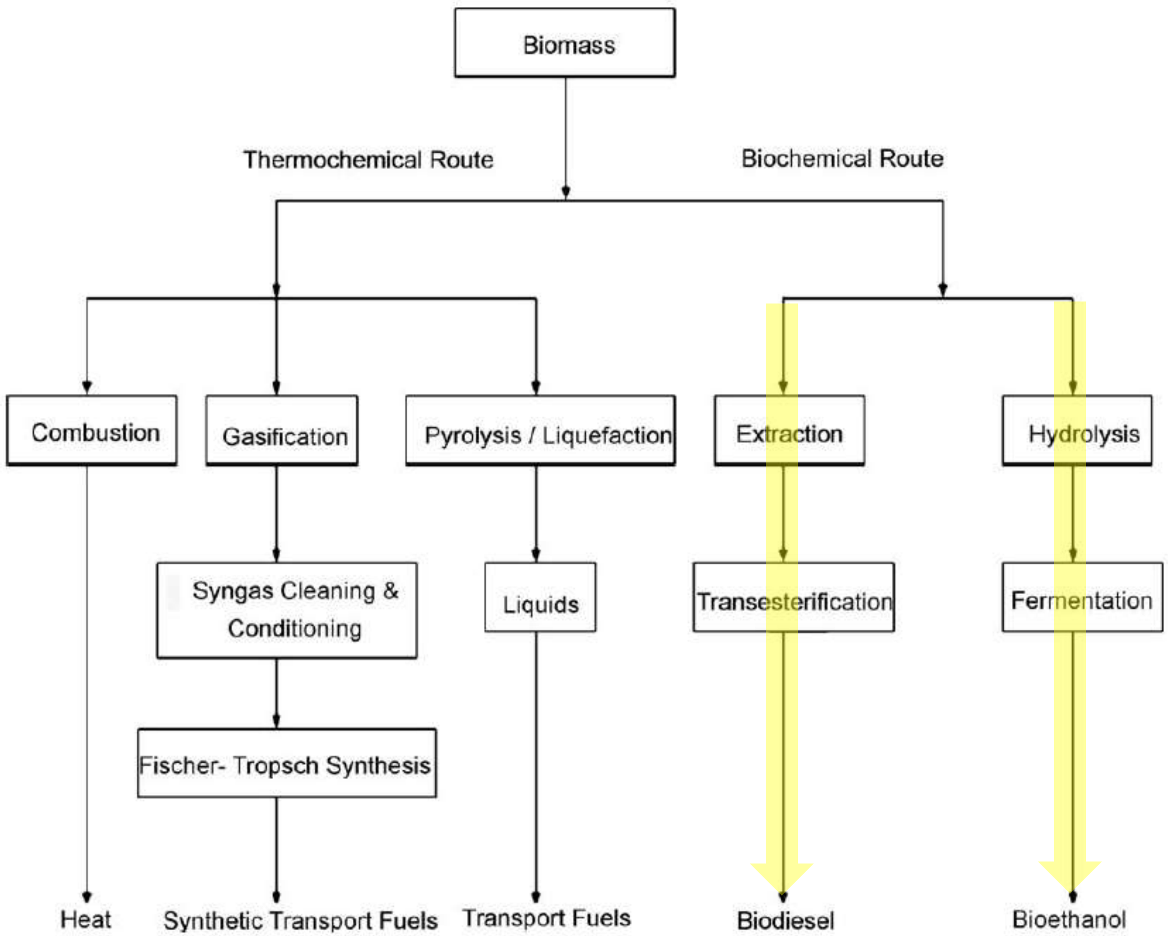


(Huber, 2006)

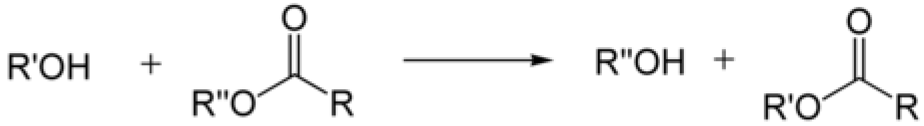
Component	Percent dry weight (%)	Description
Cellulose	40–60	A high-molecular-weight (10^6 or more) linear chain of glucose linked by β-glycosidic linkage. This chain is stable and resistant to chemical attack
Hemicellulose	20–40	Consists of short, highly branched chains of sugars (five-carbon sugars such as D-xylose and L-arabinose, and six-carbon sugars such as D-galactose, D-glucose, and D-mannose) and uronic acid. Lower molecular weight than cellulose. Relatively easy to be hydrolyzed into basic sugars
Lignin	10–25	A biopolymer rich in three-dimensional, highly branched polyphenolic constituents that provide structural integrity to plants. Amorphous with no exact structure. More difficult to be dehydrated than cellulose and hemicellulose

(Zhang, 2010)

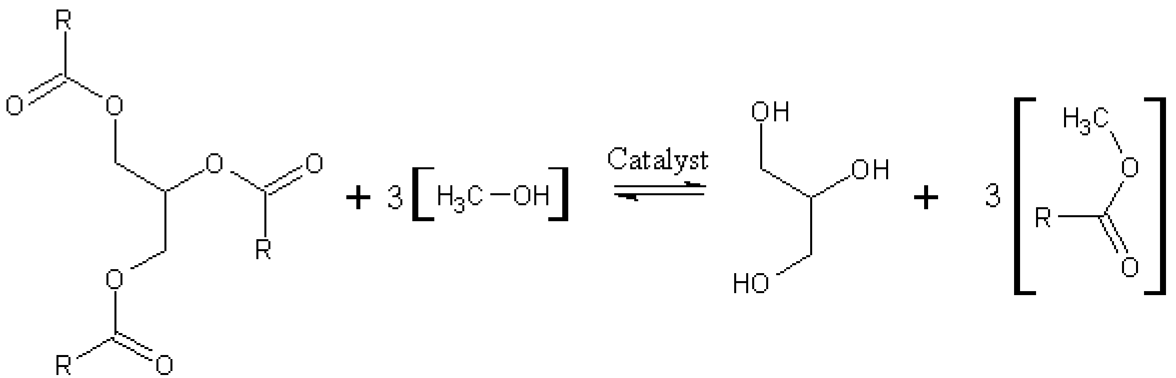
Principal Biomass Conversion Routes



Biochemical: Transesterification



alcohol + ester → different alcohol + different ester



Triglyceride Methanol (3) Glycerol Methyl Esters (3)

Used vegetable oil inside

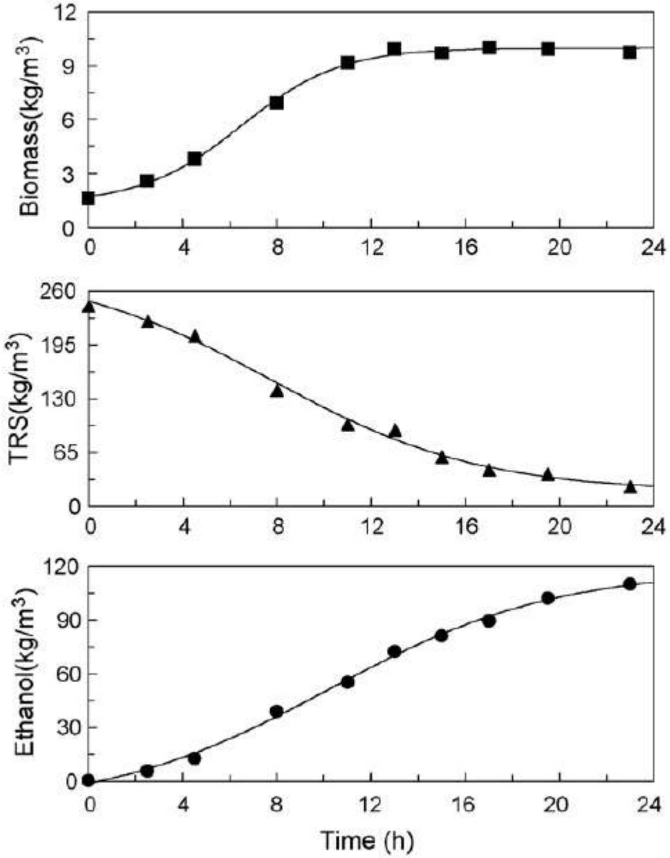
Biochemical: Fermentation

$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$

Sugars directly fermentable

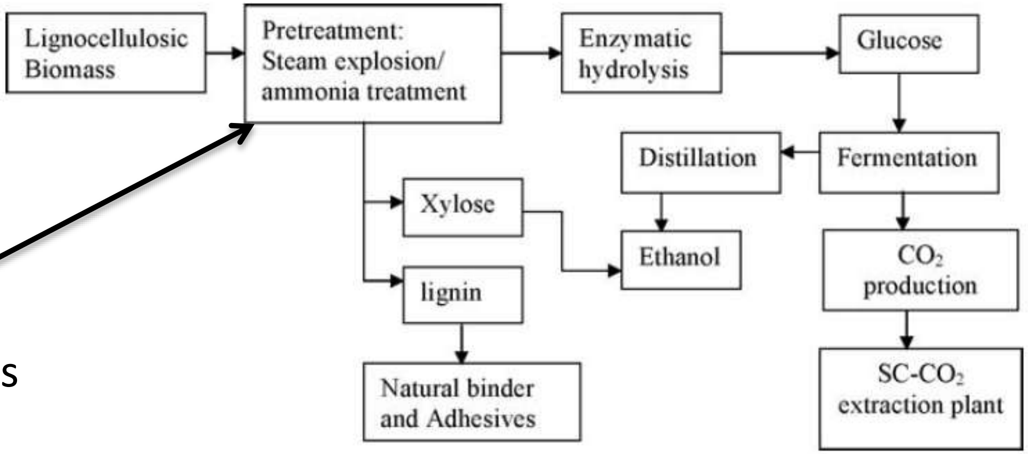
Cellulosic material-pretreatment required

Issue: Consumption of TRS for metabolism and reproduction of organisms



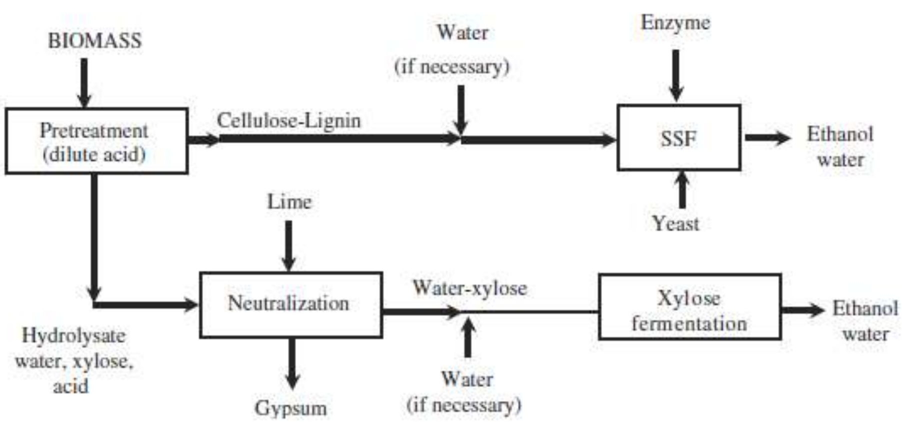
(Rivera, 2007)

Fermentation of Ligno-Cellulosic Biomass



Pretreatments before fermentation

Fig. 13. Conversion of lignocellulosic biomass to ethanol.



Thermophysical Conversion: Gasification

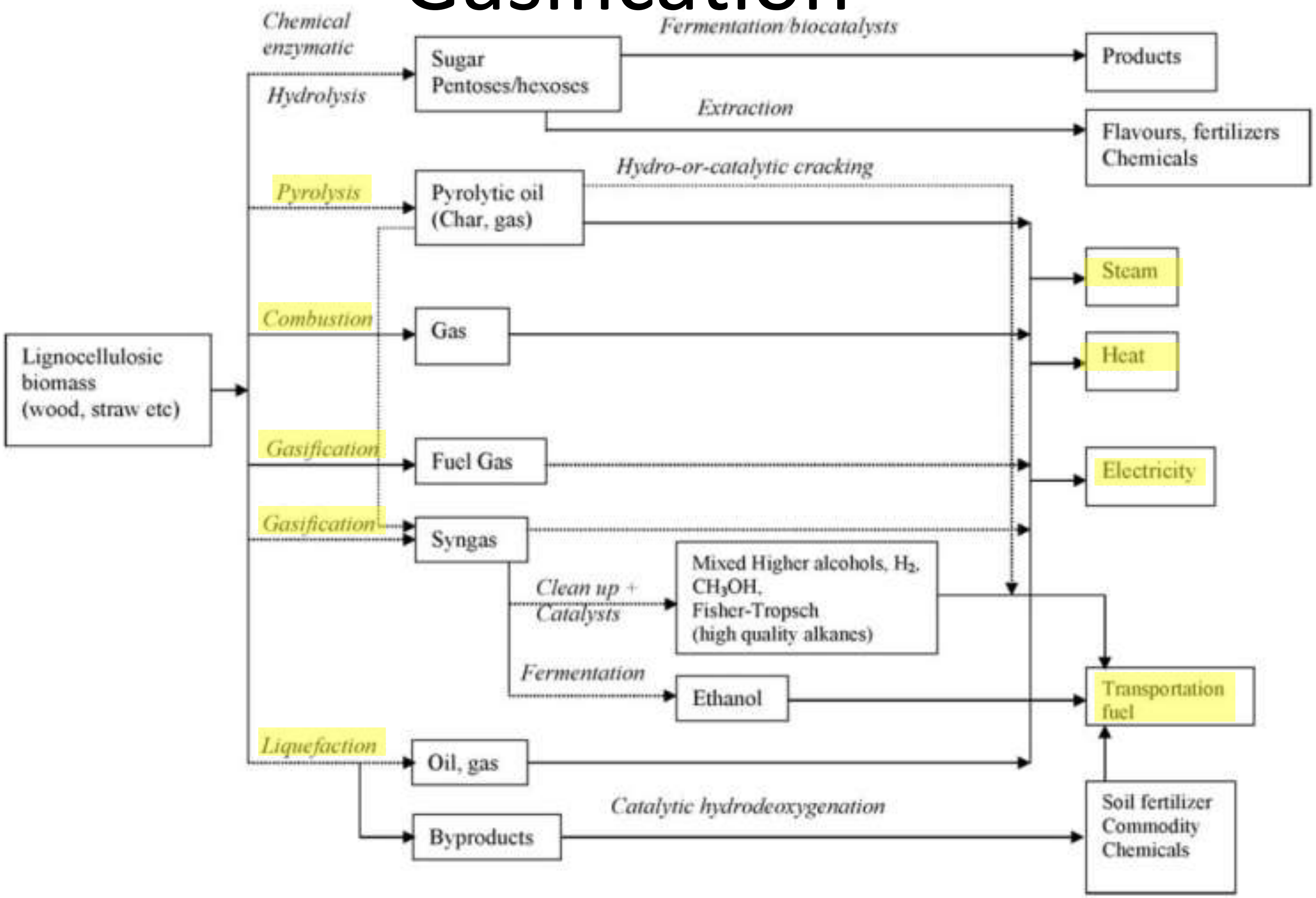


Fig. 16. Forest based and lignocellulosic biorefinery. www.biorefinery.euroview.eu [52].

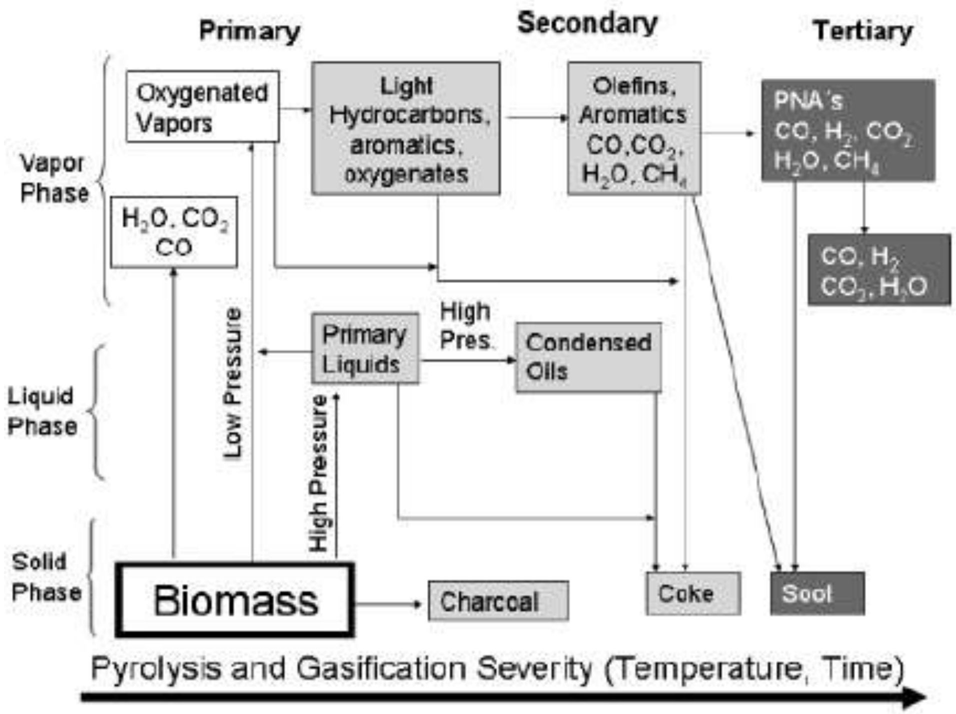
Conventional Gasification

Table 7. Fundamental Reactions and Enthalpy of Selected Cellulose Gasification Reactions[a]

classification	stoichiometry	enthalpy (kJ/g-mol) ref temp 300 K
pyrolysis	$C_6H_{10}O_5 \rightarrow 5CO + 5H_2 + C$	180
	$C_6H_{10}O_5 \rightarrow 5CO + CH_4 + 3H_2$	300
	$C_6H_{10}O_5 \rightarrow 3CO + CO_2 + 2CH_4 + H_2$	−142
partial oxidation	$C_6H_{10}O_5 + {}^1/_2\, O_2 \rightarrow 6CO + 5H_2$	71
	$C_6H_{10}O_5 + O_2 \rightarrow 5CO + CO_2 + 5H_2$	−213
	$C_6H_{10}O_5 + 2O_2 \rightarrow 3CO + 3CO_2 + 5H_2$	−778
steam gasification	$C_6H_{10}O_5 + H_2O \rightarrow 6CO + 6H_2$	310
	$C_6H_{10}O_5 + 3H_2O \rightarrow 4CO + 2CO_2 + 8H_2$	230
	$C_6H_{10}O_5 + 7H_2O \rightarrow 6CO_2 + 12H_2$	64

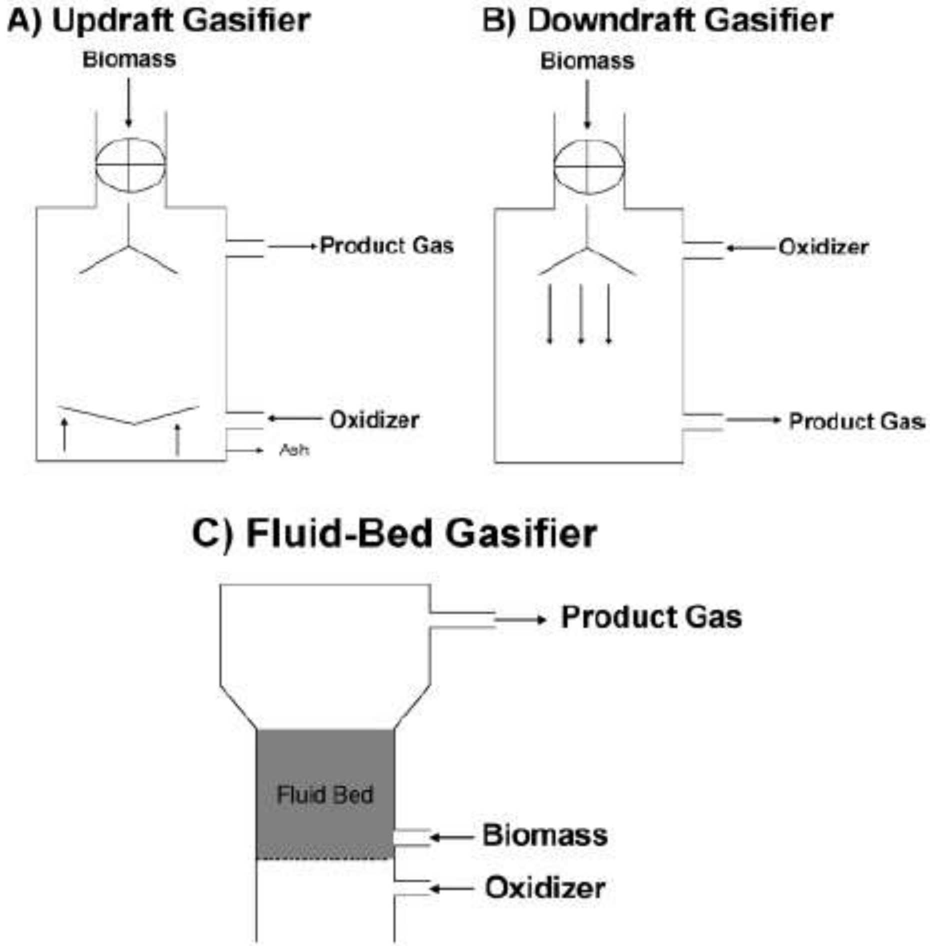
[a] Adapted from Klass.[2]

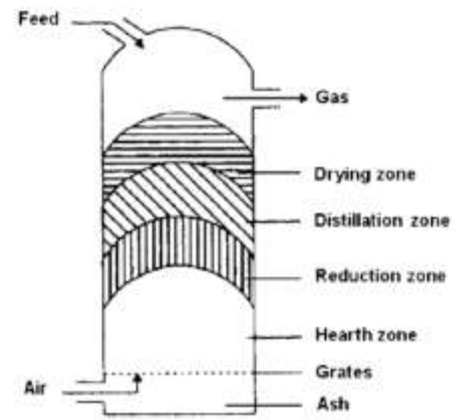
Thermochemical: Gasification



(Huber, 2006)

Conventional Gasifiers





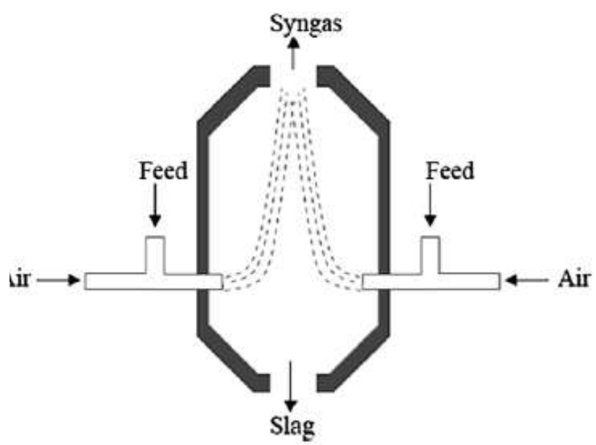


Fig. 7. Configuration of the entrained flow gasifier [48].

Plasma Torch and Gasifier

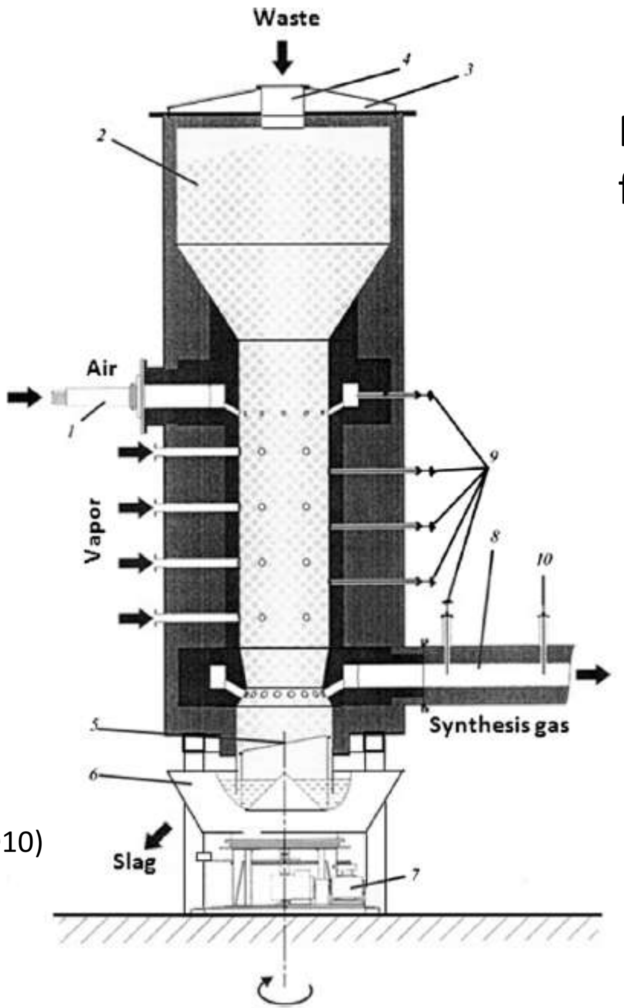
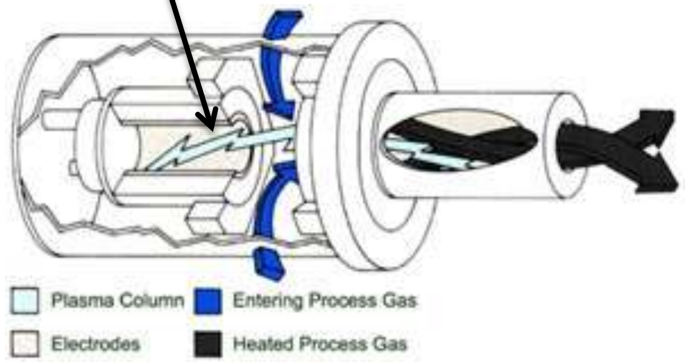


Fig. 9. Configuration of a shaft-type plasma gasifier reactor. (1) plasma generator, (2) bin with waste, (3) cover, (4) charging batch, (5) fire grate, (6) bath with water for quenching the slag, (7) fire grate rotation drive, (8) gas duct, (9) temperature sensors and (10) gas sampling [84].

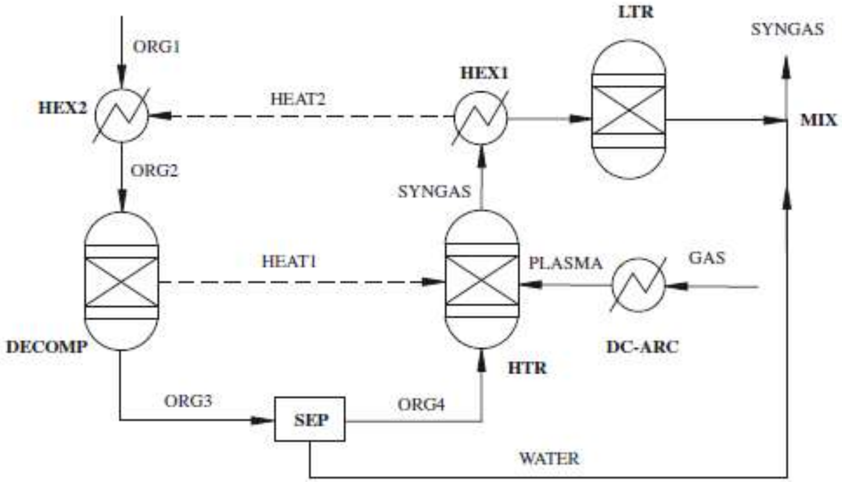
(Zhang, 2010)

Plasma generation is "remote" from fed species



(recoveredenergy.com)

Plasma Gasification, Model and Simulation



Aspen Plus Model

$$\eta_{PG} = \frac{\dot{m}_{Syngas} \cdot LHV_{Syngas}}{\dot{m}_{RDF} \cdot LHV_{RDF} + (W_{Torch} + W_{ASU})/\eta_{el}}$$

Compared simulated cases with enhanced O_2

Gasifier + ASU tandem cases compared

ASU = Air Separation Unit

(Minutillo, 2009)

	Case A	Case B	Case C
Syngas, LHV (MW)	15.97	15.48	14.74
Torch power consumption, W_{Torch} (MW)	4.26	3.44	2.75
ASU power consumption, W_{ASU} (MW)	–	0.157	0.195
η_{PG} (%)	63.6	66.7	69.1
Syngas composition (mol%)			
H_2	21.04	31.49	28.65
CO	33.79	38.73	37.37
CH_4	5.97	–	–
CO_2	–	0.42	1.41
H_2O	11.68	12.50	14.91
N_2	26.97	16.32	17.12
HCl	0.32	0.31	0.31
H_2S	0.22	0.22	0.22
COS	0.02	0.01	0.01
HHV (MJ/kg)	10.50	11.06	10.13
LHV (MJ/kg)	9.55	10.10	9.20

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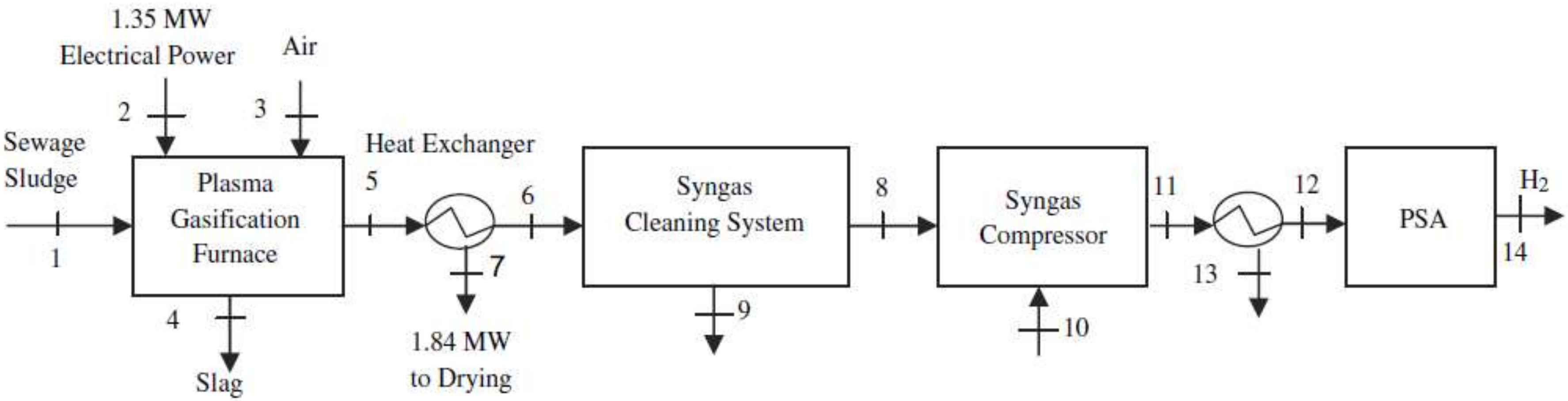
Process Analysis



(Kalinici, 2011)

Exergy = available energy

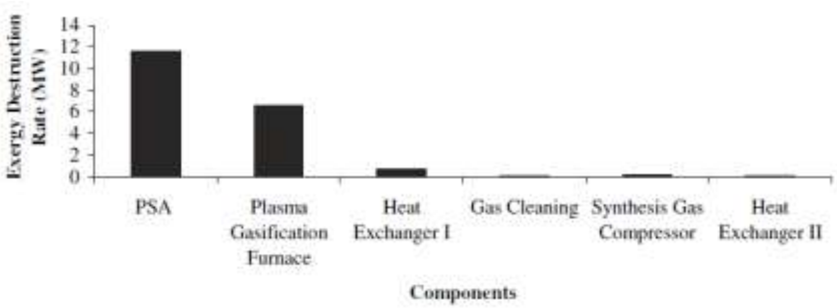


Fig. 2 – Exergy destruction rates of components.

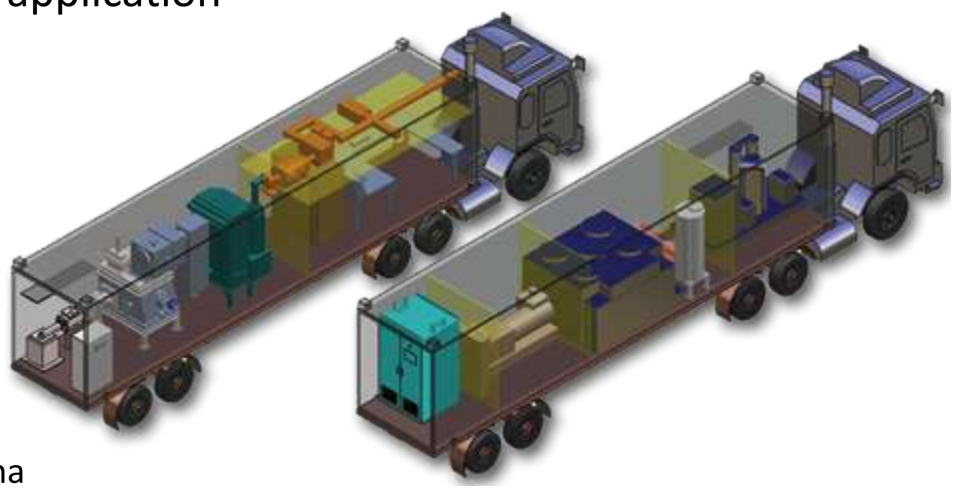
Scaling of Plasma Gasification

Based on Minutillo paper (15 MW plasma sources/ 471,000 kg/day)

Torch capacity to process 1 ton/day in small scale system (Allmon):

=29 kW

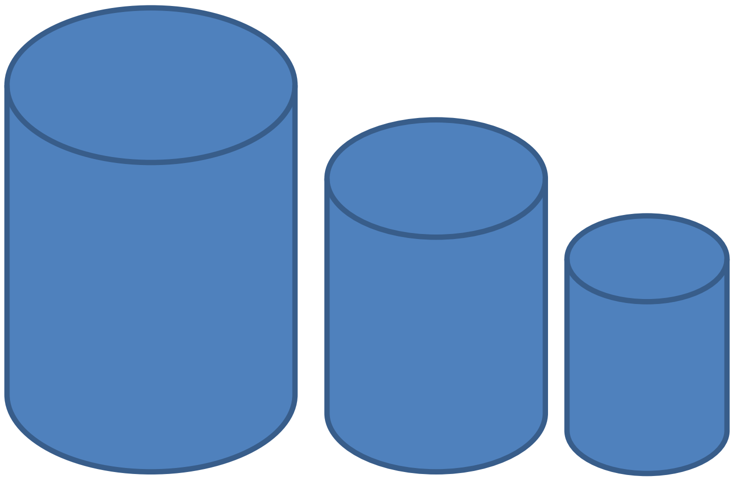
Smaller sources exist, e.g., sources for ICP mass spectrometer ionizers, but very different application



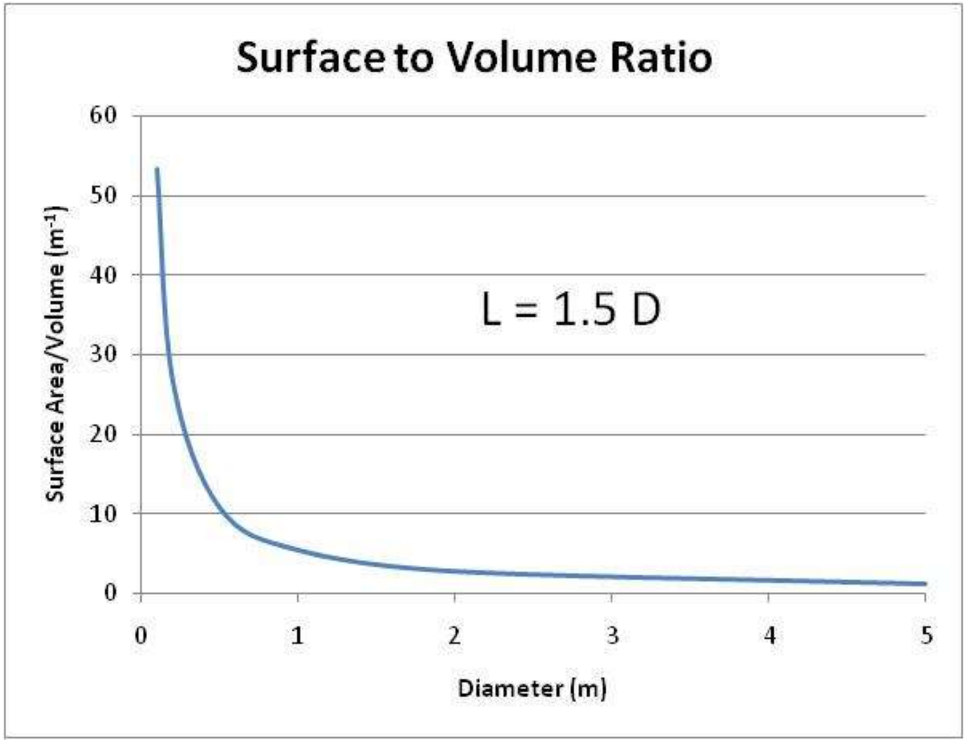
Arc Master I Portable Plasma Gasification System, CBP

Scaling Issues

Constant L/D Ratio



SA/V Increasing →



__Heat Loss__

__Surface Reaction-quenching__

__Energy Efficiency__

Scaling Continued

- Control of residence time in plasma heated zone is function of several variables (falling rate, fluidization, size of plasma plume, etc.); difficult to maintain t in smaller geometry.
- Continuous feeding (vs. batch) will be more difficult for same reasons.

Conclusions/Recommendations

- Plasma gasification is clearly viable
- The case for waste destruction is strong
- Self sustaining or net energy production depends on the waste
- Biomass feedstock processing is attractive but seems like a (local) logistical nightmare (for mobile DoD application)
- Downscaling to 1 ton/day may not be viable; research needed

Plasma Waste to Energy System

Ron Omley, P.E.

Chief Environmental Engineer

HQ AFSOC

Asset Management Division

28 Sep 2011

Agenda

- ***Background***
- ***Hurlburt Plasma project***
- ***Questions/Discussion***

Why are we doing this?

Save $$$

Solve Open Pit burning problem

Reduce environmental risks

100% Recycling

Reduce GHG emissions

Produce aggregate

Improve methods

Conserve scarce resources

Waste diversion

Meet EO 13423 & 13514 goals

Produce energy

Reduce groundwater pollution

How Does the Process Work?

Waste +

Plasma Furnace

+

Plasma Torch

+ Small volume of Air

Gasification *(Fast)*

Shock Cooling & Cleaning of Syngas (fuel)

Gas Engine
Recovers Chemical Energy

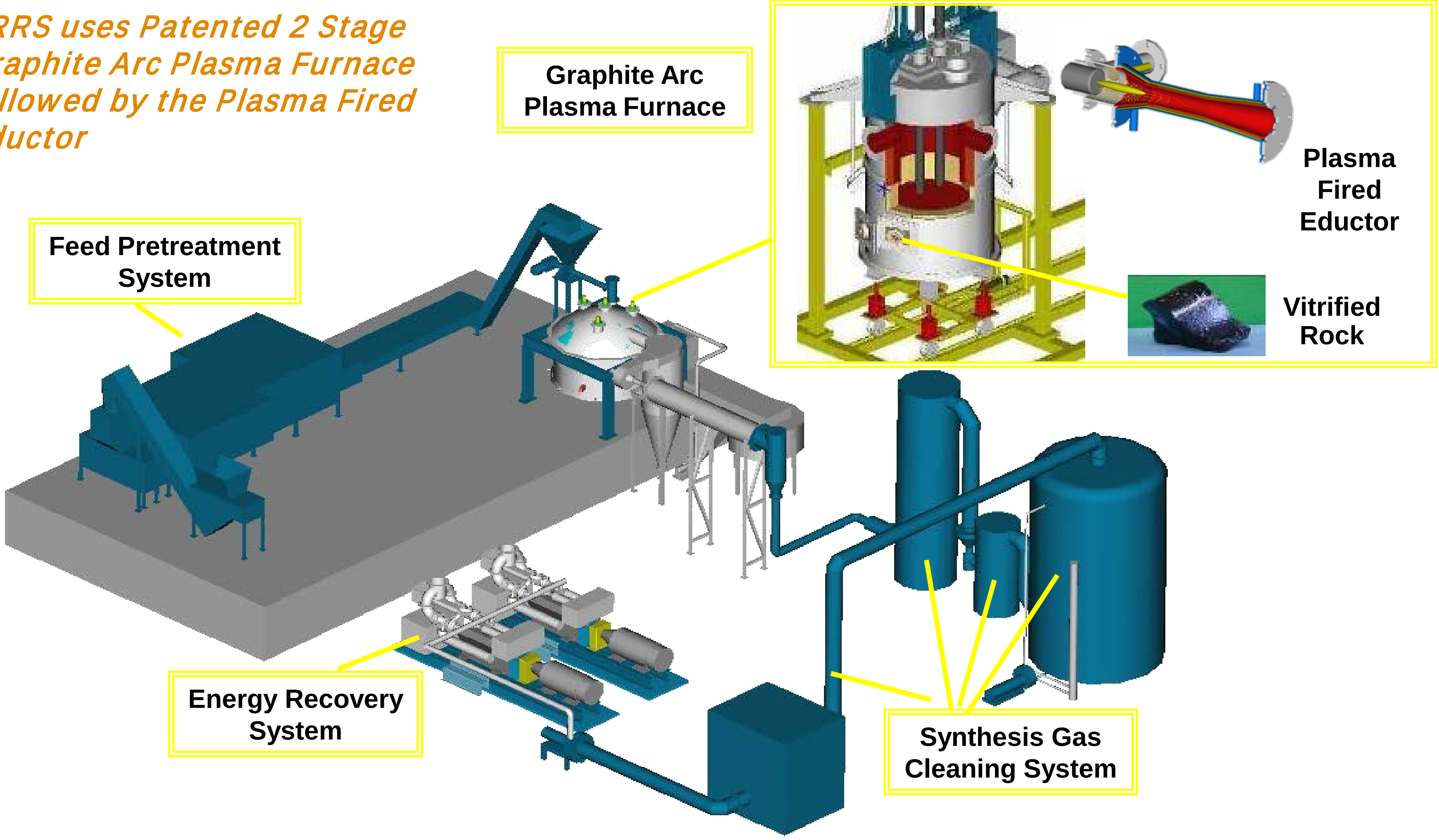
No Secondary wastes
100% Volume Reduction

- Small Systems
- Scalable
- Energy Recovery
- No Dioxins / Furans
- No Residual Waste

Reduces GHG → Carbon Credits

PRRS Design Layout

PRRS uses Patented 2 Stage Graphite Arc Plasma Furnace followed by the Plasma Fired Eductor



Hurlburt’s Plasma System

Shredder

Sieve

Metal Removal System

Eddy Current Removal

Screw Auger

Furnace Mezzanine

Plasma Furnace

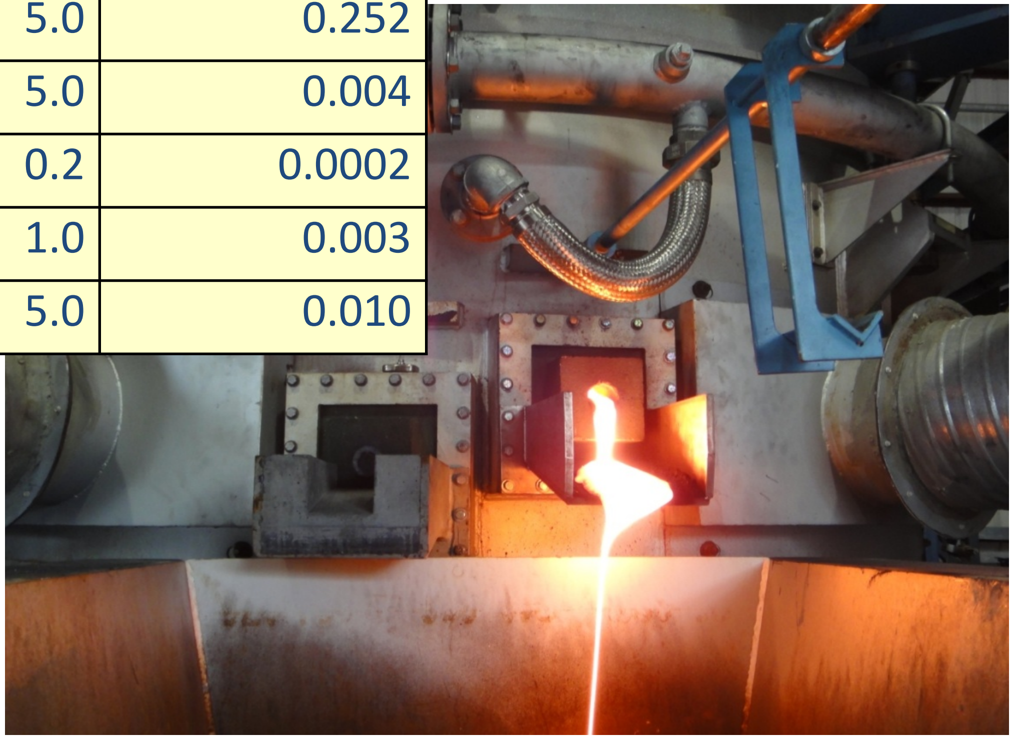
Graphite Electrodes

Inorganic Material Sinks to the Bottom

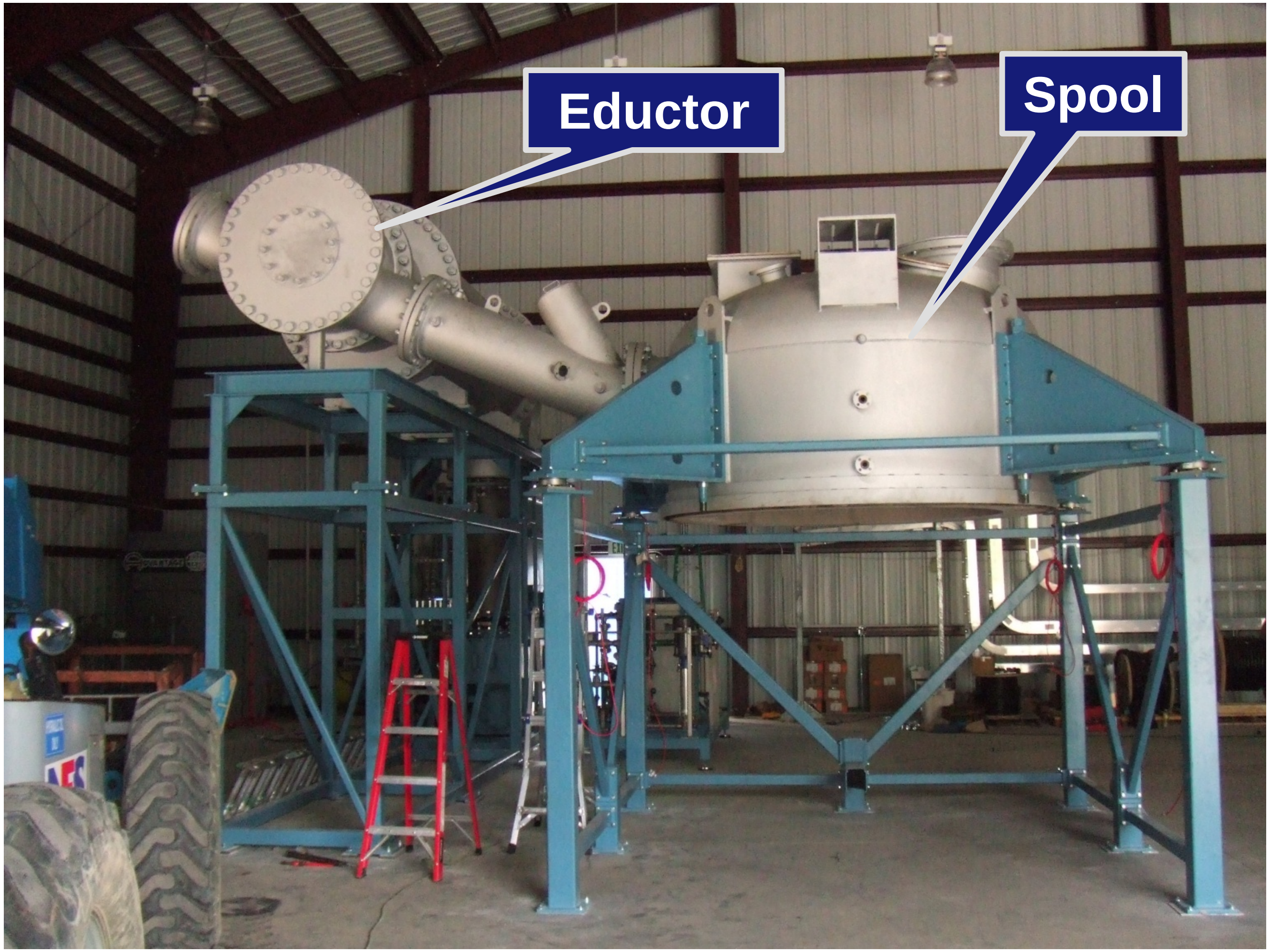
Molten Metal Oxides

TCLP results from Hurlburt

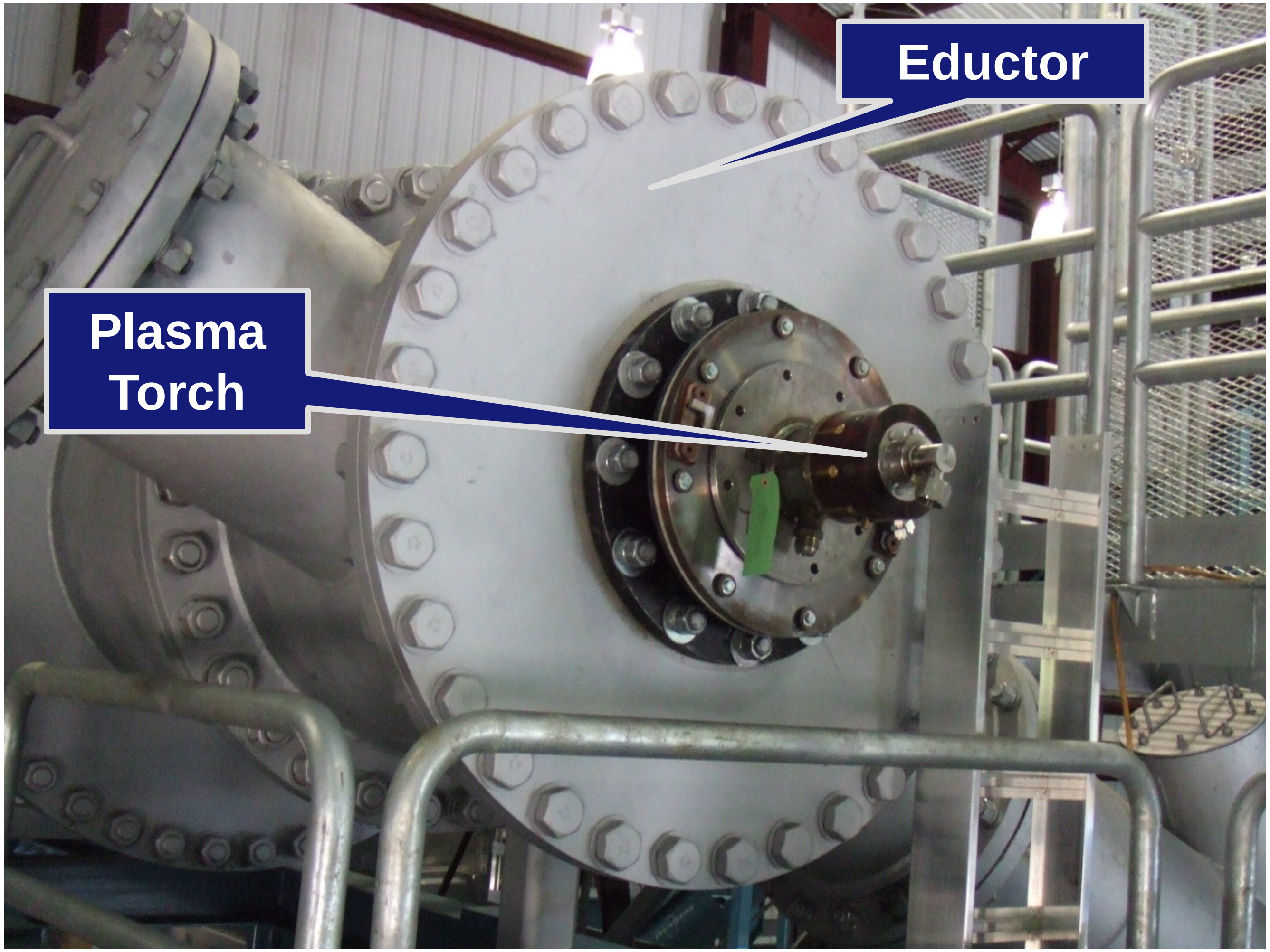
Contaminant	EPA Hazardous Waste #	Regulatory level (mg/L)	Slag concentration (mg/L)
Arsenic	D004	5.0	0.002
Barium	D005	100.0	1.253
Cadmium	D006	1.0	0.001
Chromium	D007	5.0	0.252
Lead	D008	5.0	0.004
Mercury	D009	0.2	0.0002
Selenium	D010	1.0	0.003
Silver	D011	5.0	0.010



Crucible Spool and Eductor

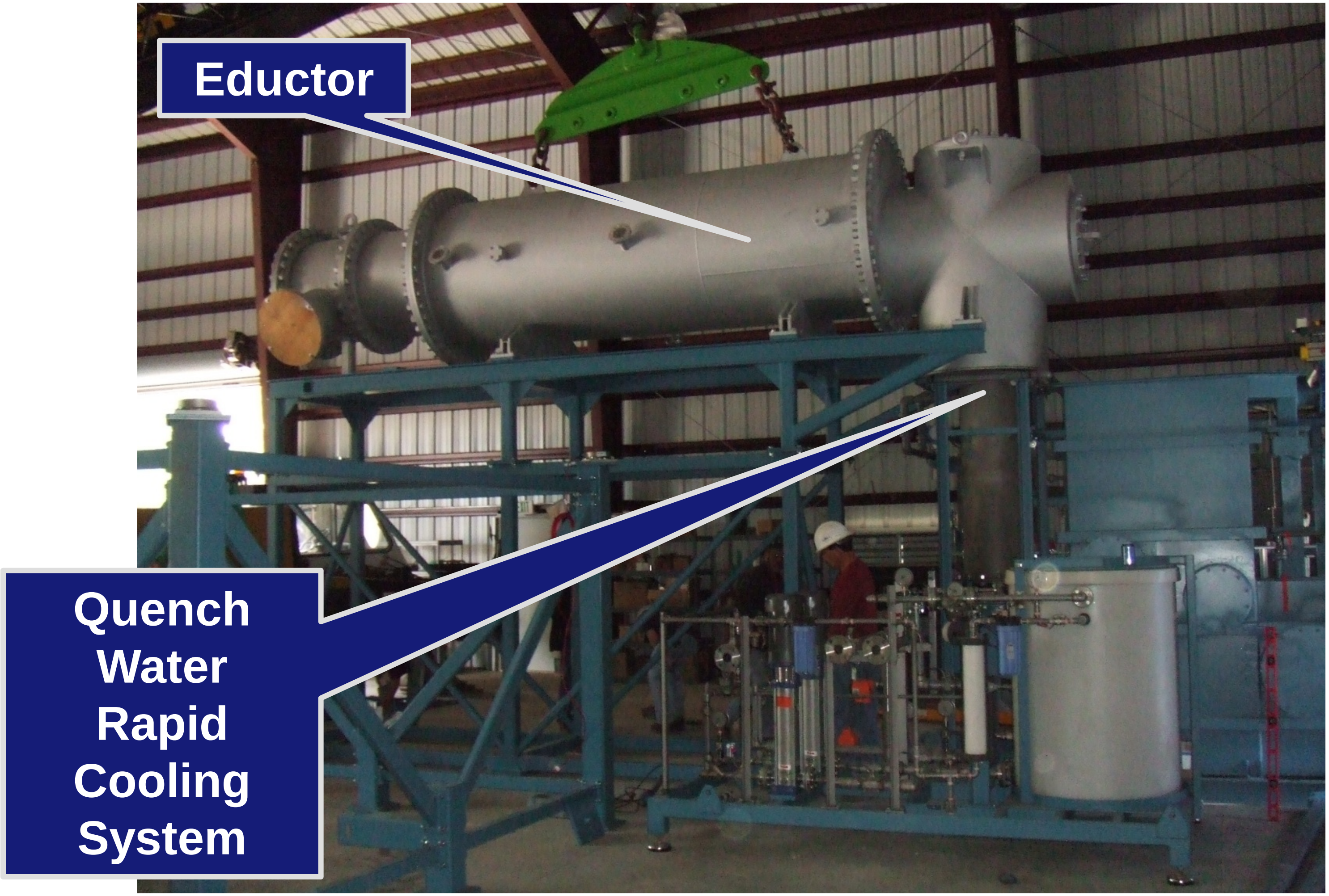


Plasma Torch Installed

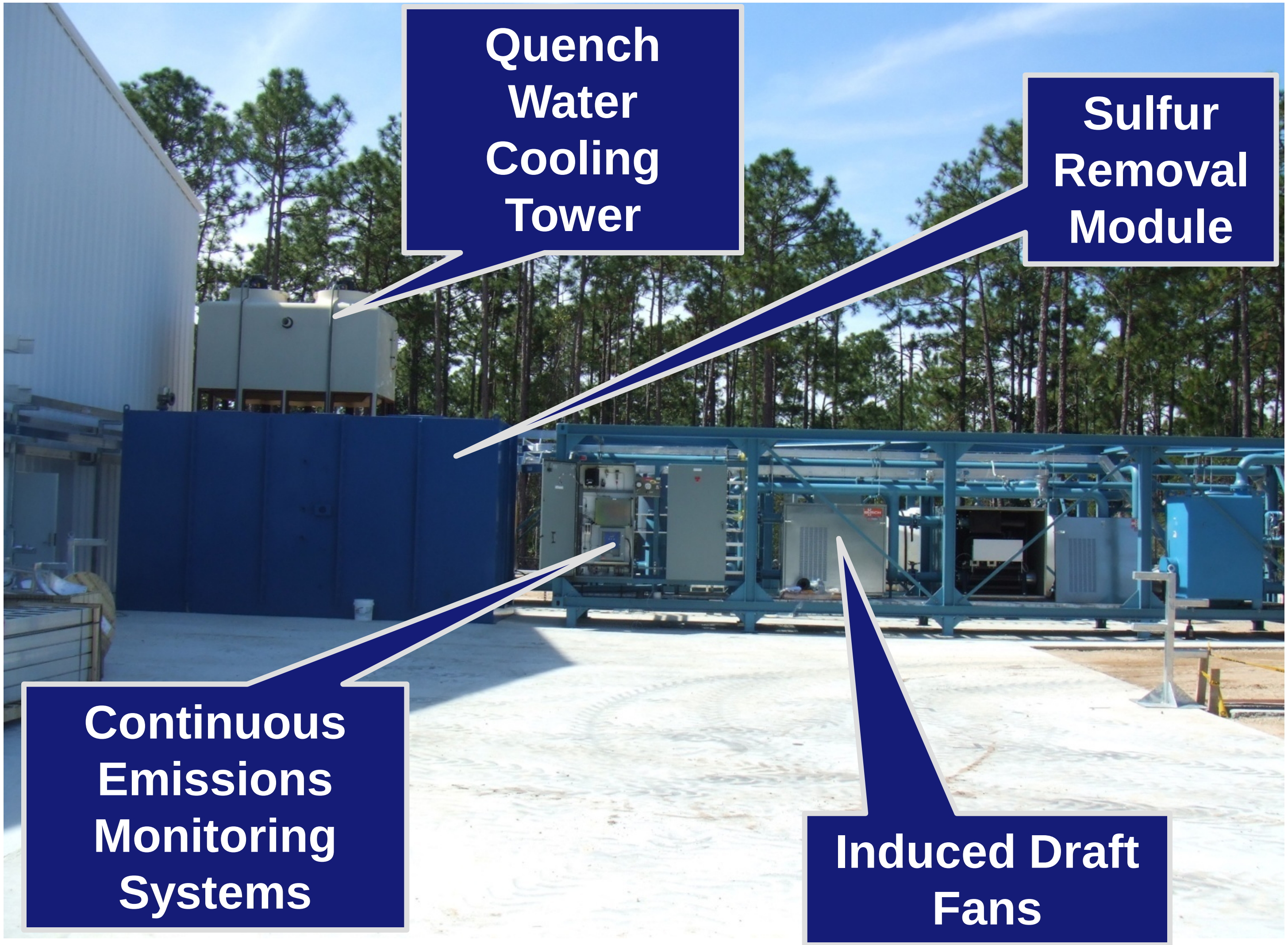


Plasma Torch Test

Eductor Being Connected to Quench System



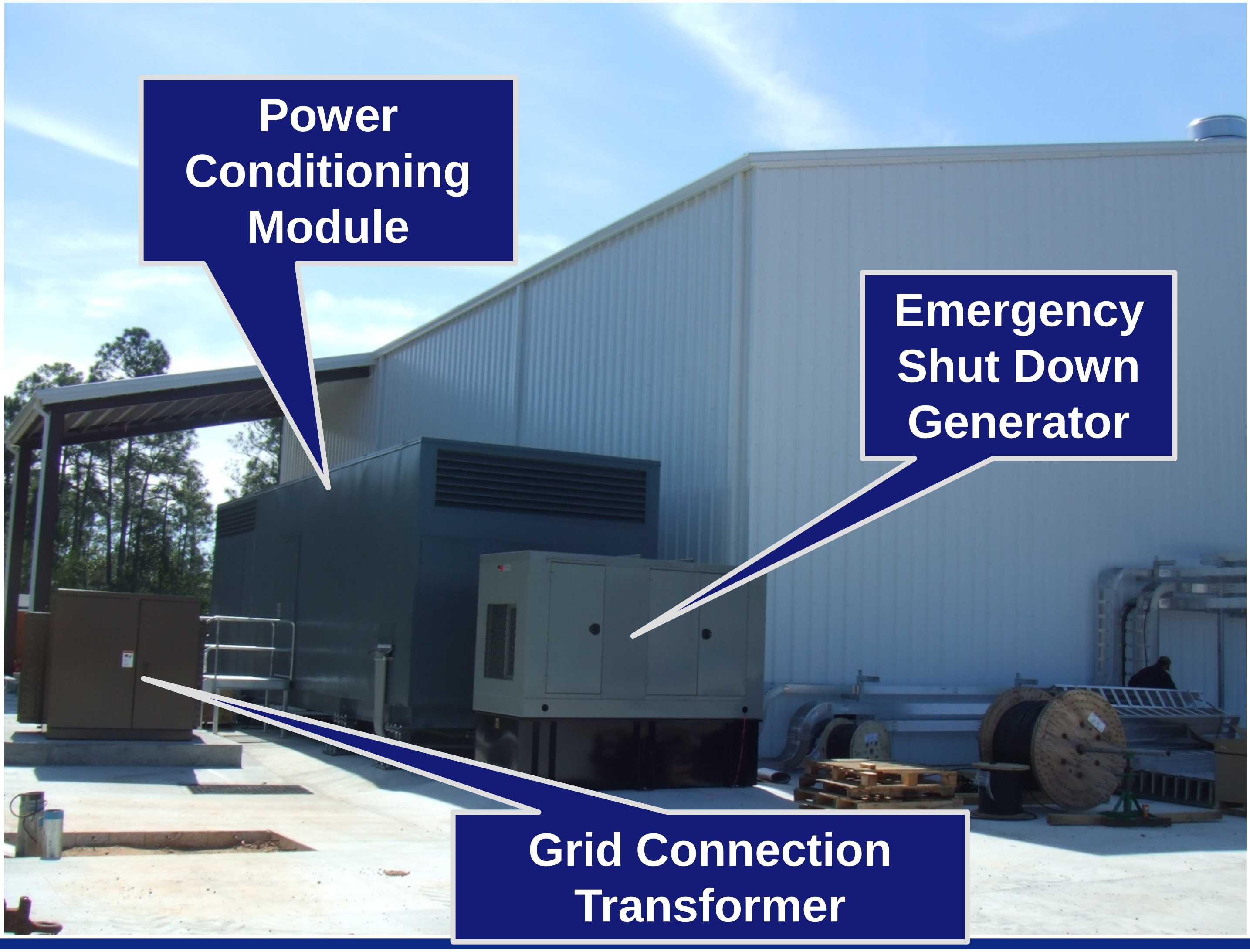
Syngas Cleaning Equipment



Syngas Flaring Tower

Jenbacher 12 Cylinder

Electrical Conditioning Module



Plasma System Animation

Video of Hurlburt Field Operation

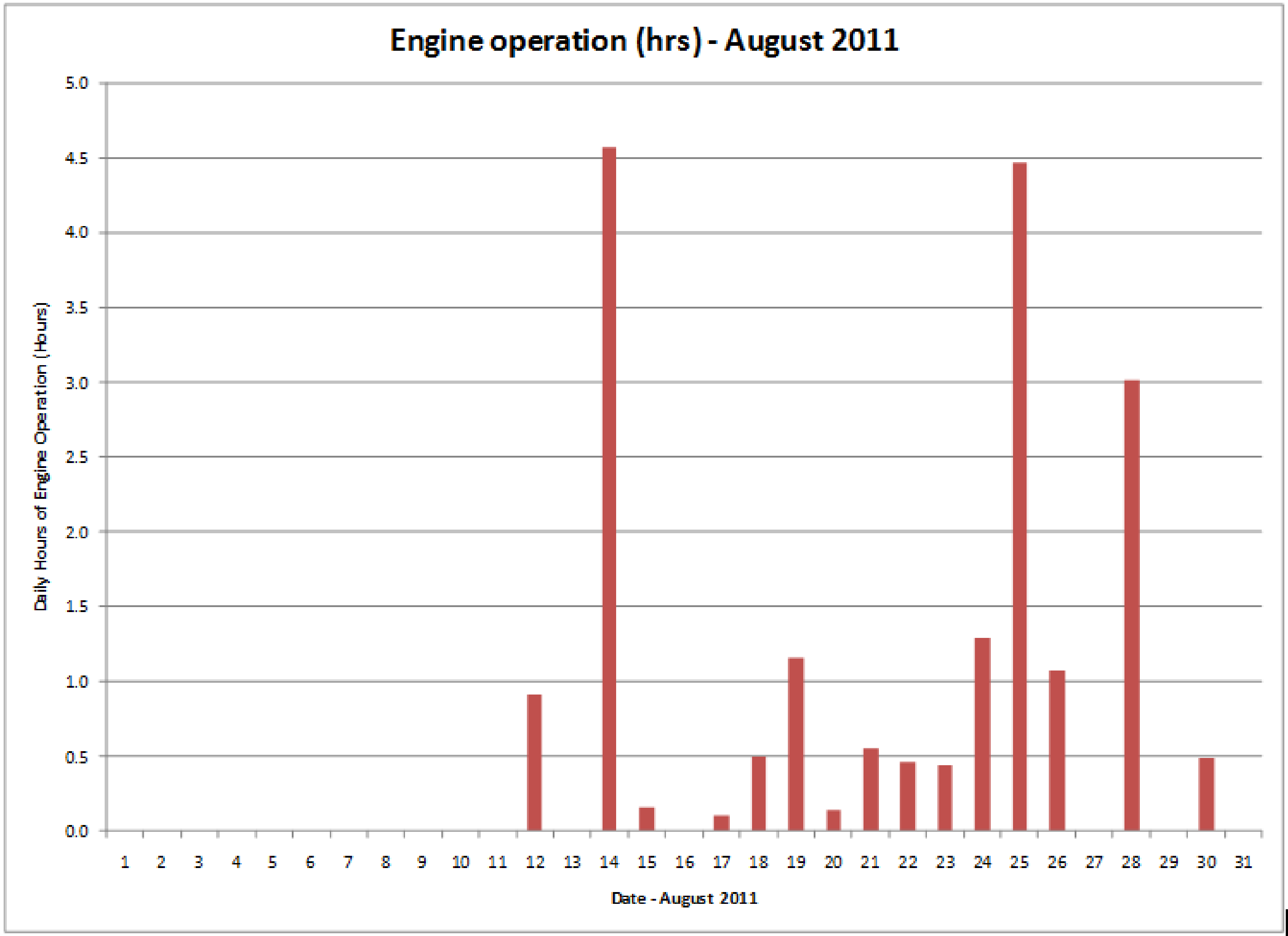
Plasma Waste to Energy System Update

Ron Omley, P.E.

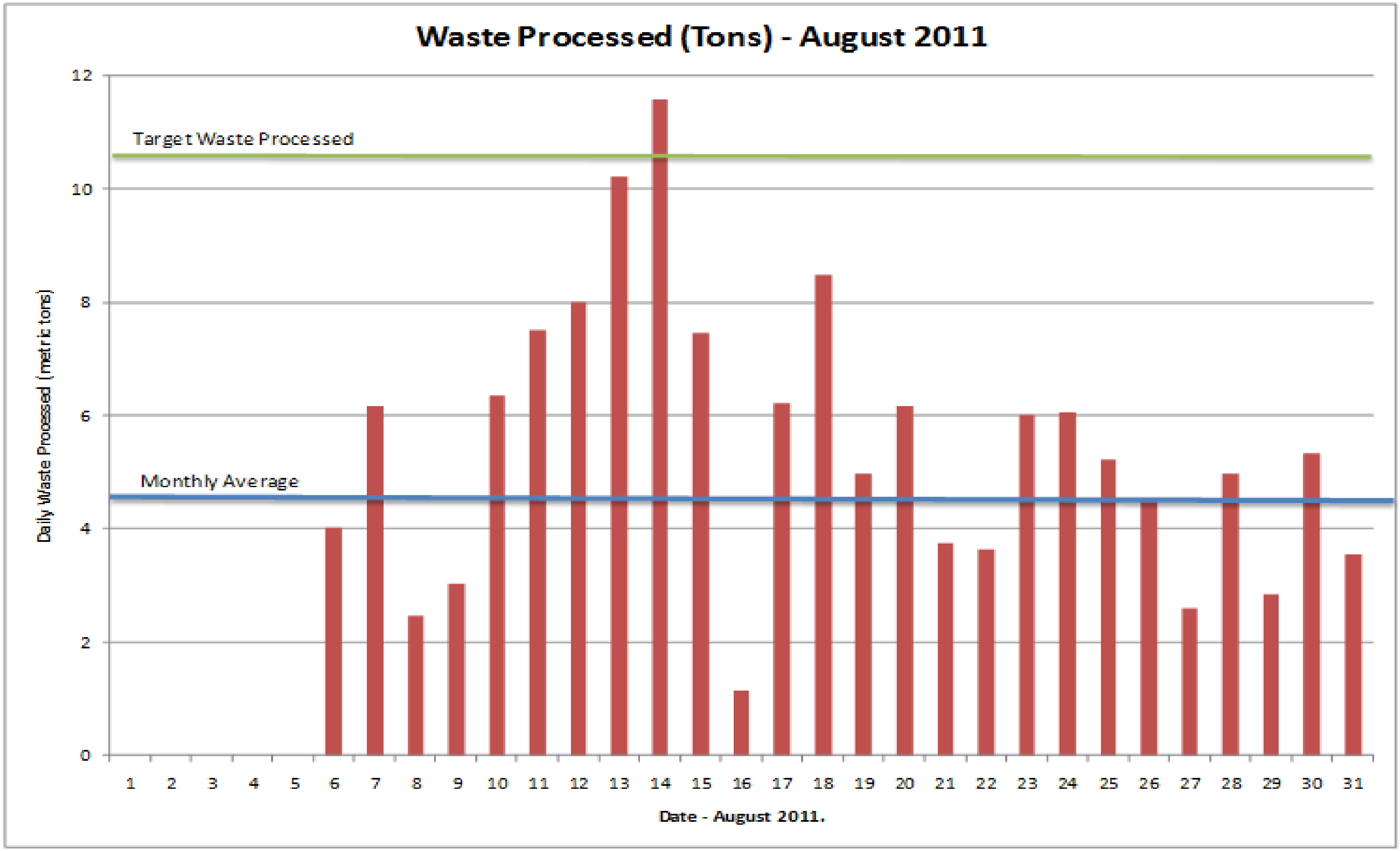
AFSOC/A7AV

28 Sep 2011

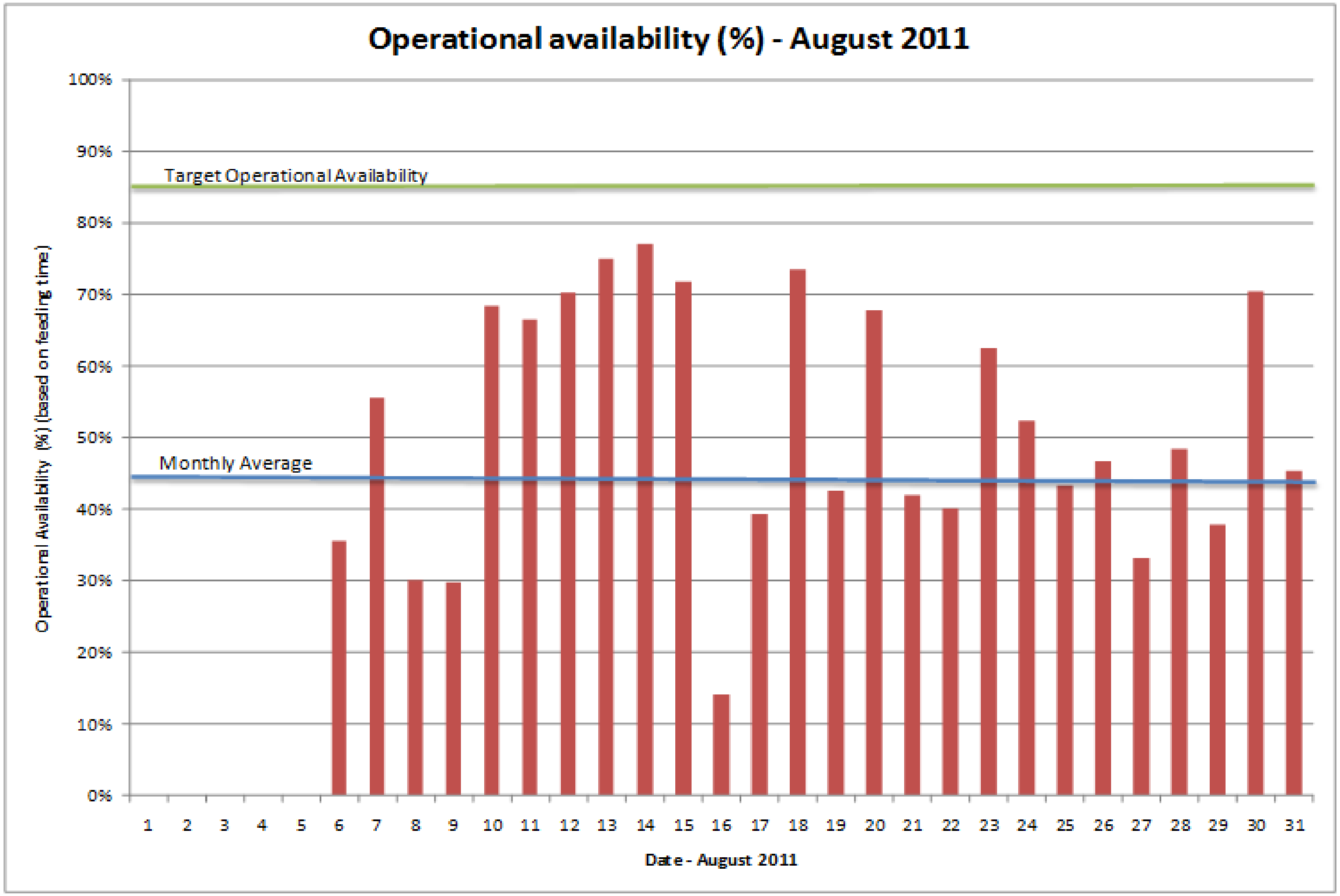
August Engine Operation



August Waste Processed



August Operational Availability



Highlights

- System has demonstrated the gasification technology works
- 4.5 TPD Average waste gasified in August
- Engine operational availability is increasing, but not rapidly
  - We would like to see a gas sweetening system added (techjet) to adjust calorific values upward as needed to allow Jenbacher operation 24/7
- Major downtime in August was due to cold top issues
  - The furnace is currently being cooled down to resolve this problem.
- Other downtime issues have been resolved as follows:
  - H2S Scrubber.
    - Process cleaning/maintaining has been modified reduce time
  - "electrode regrab" problems
    - A new motion system was fabricated to automate regrab
  - Modification of electrode position have improved tapping.
  - Modifications to the venturi scrubber and better cooling of quench water have reduced gas cleaning maintenance (particulate carryover decreased)

Where Are We?

- **Needed Improvements**
  - *Upsize/improve system front end and shredder*
  - *Ability to island the system*
    - *Power outages lasting more than two hours cause:*
    - *Furnace Freezes*
    - *Two week cool down and restart effort for system*
    - *Waste stream diverted to the landfill*
  - *Boiler with steam turbine generator system*
    - *Energy neutrality is a work in progress*
    - *Flaring tower requires a portion of the syngas*
    - *New flame arrestor required to improve efficiency*
    - *Jenbacher syngas requirements (stoichiometry)*
  - *SYNGAS sweetening system*

Where Are We?

- **_Needed Improvements Continued_**
  - _Porcupine Screw Auger System_
    - _Landfill ban on sludge disposal_
    - _Dried sludge is converted to syngas_
  - _No medical waste treated to date_
  - _No hazardous waste treated to date_
- **_Improvements Already Made to the System_**
  - _Quench water system modified and improved_
  - _Water treatment skid modified and improved_
  - _Better quality control on supplies_
  - _Quench water force main allows water to be sent to the County_
  - _Improved water removal system_

Where Will This Work?

- Deployed locations
- High landfill tipping fees
- High electrical costs
- High hazardous waste disposal costs
- High heating demand/Central steam plant
- Opportunity for local partnerships
- Research Opportunities
  - Dual Fuel Test
  - Fuel Cell Test
  - Fischer-Tropsch Process
  - Biodiesel From Algae Using CO2 From DSW
  - Micro turbines/steam turbines/organic rankine cycle

Summary

- ***PRRS technology can:***
  - ***Save money***
  - ***Convert waste to energy, i.e. electrical and heat***
  - ***Recover waste stream products***
  - ***Reduce green house gas emissions***
  - ***Divert waste from landfills***
  - ***Help exceed mandated EO 13423 and 13514 goals***
- ***Opens the door for future DoD and National application***
- ***Help solve tough war fighter problems!***

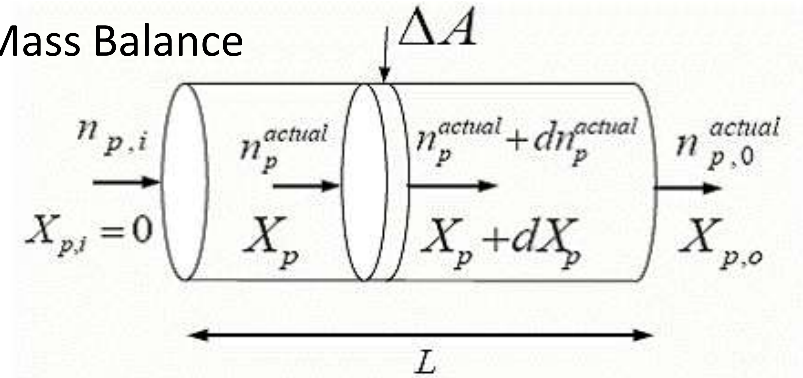
Questions?

Perspectives on Plasma Gasification for Waste Processing and Energy Consumption

Prof. Ronald S. Besser
Chemical Engineering and Materials Science
Stevens Institute of Technology
Hoboken, NJ

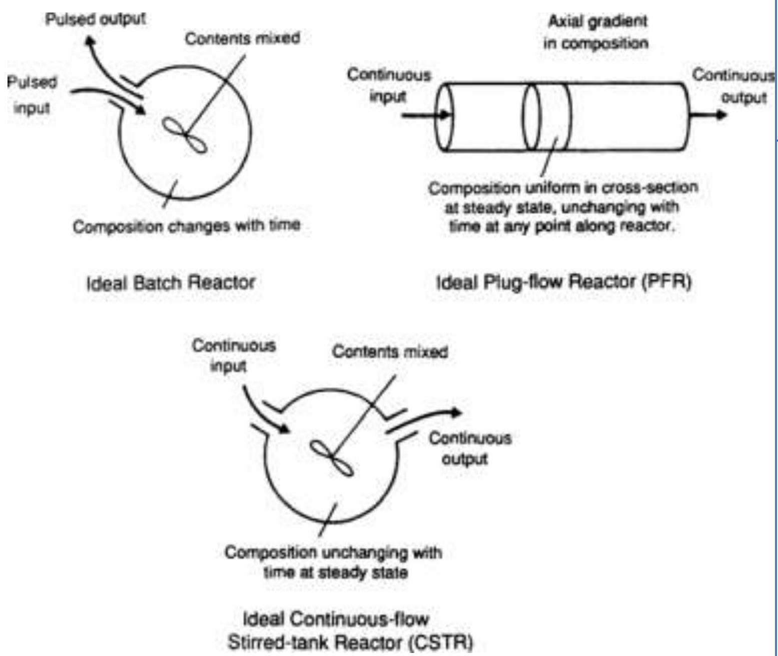
Perspective: Chemical Reaction Engineering / Chemical Reactor Design and Analysis

Mass Balance



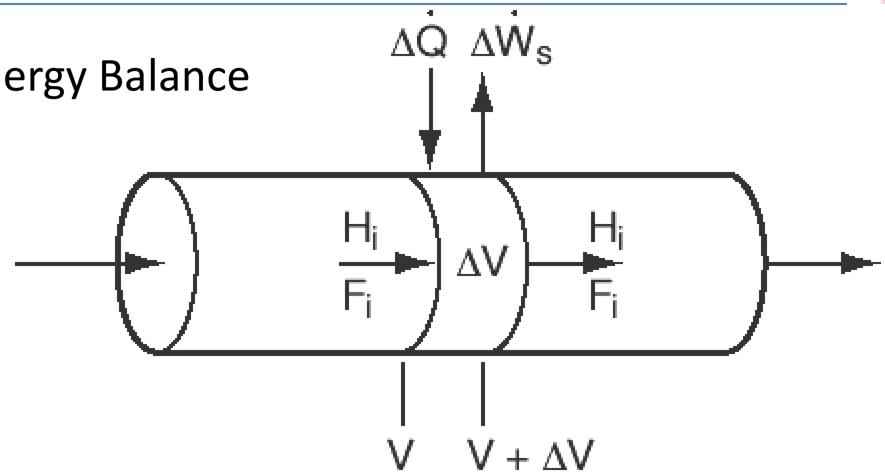
$$\begin{pmatrix}\text{mass accu-}\\ \text{mulation}\\ \text{rate}\end{pmatrix} = \begin{pmatrix}\text{mass flux}\\ \text{in}\end{pmatrix} - \begin{pmatrix}\text{mass flux}\\ \text{out}\end{pmatrix} + \begin{pmatrix}\text{net rate of}\\ \text{chemical}\\ \text{production}\end{pmatrix} \quad \text{or,}$$

$$\frac{dm}{dt} = \dot{m}_{in} - \dot{m}_{out} + \dot{m}_{reaction} \tag{14}$$



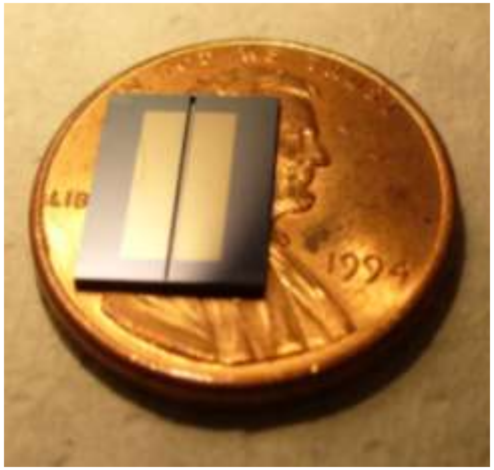
Ideal Reactor Types

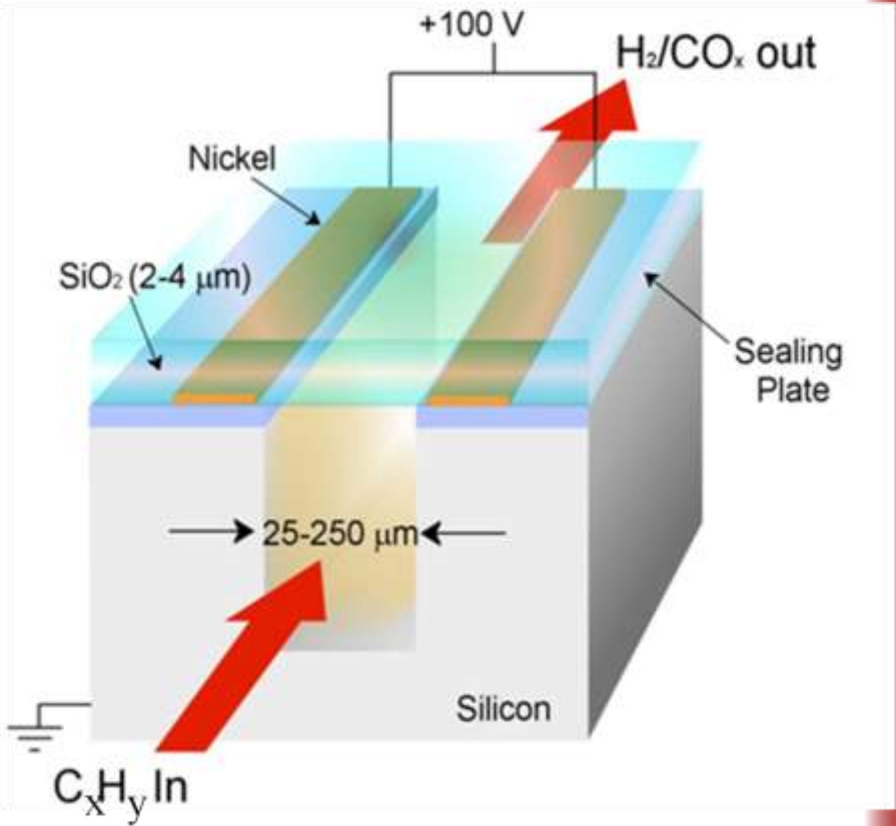
Energy Balance



$$\frac{dT}{dV} = \frac{Ua(T_a - T) + (-r_A)[-\Delta H_{Rx}(T)]}{F_{A0}(\Sigma\Theta_i F_i C_{pi} + X\,\Delta C_p)}$$

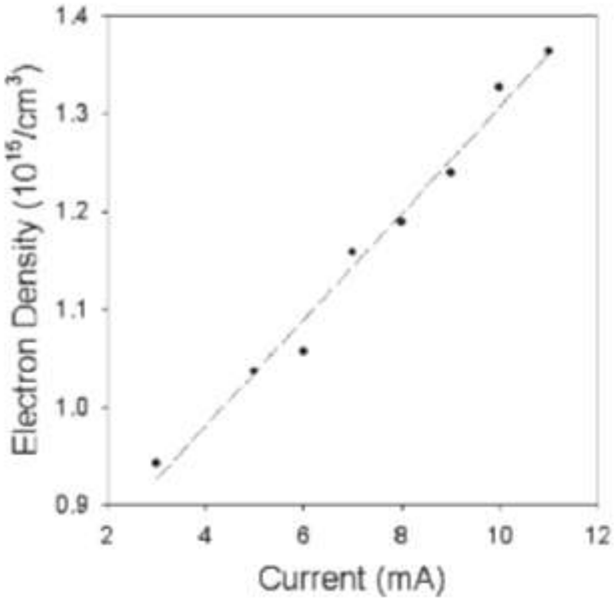
Perspective: Microplasma Reforming for Scalable Reforming of Hydrocarbons



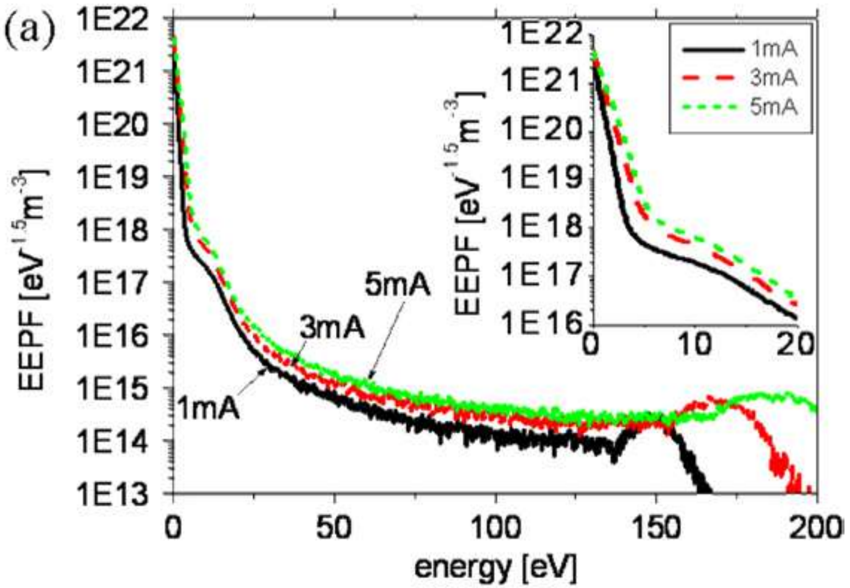


Funding:
Dr. Rob Mantz
ARO

Microplasma Reforming-New



MHCD, 220V DC, 760 torr Ar, 250 μm depth, 130 μm dia., KH Schoenbach, et. al., 2007



MHCD, 200 μm depth, 100 μm dia., 300 torr, Ar; GJ Kim, et. al., 2006

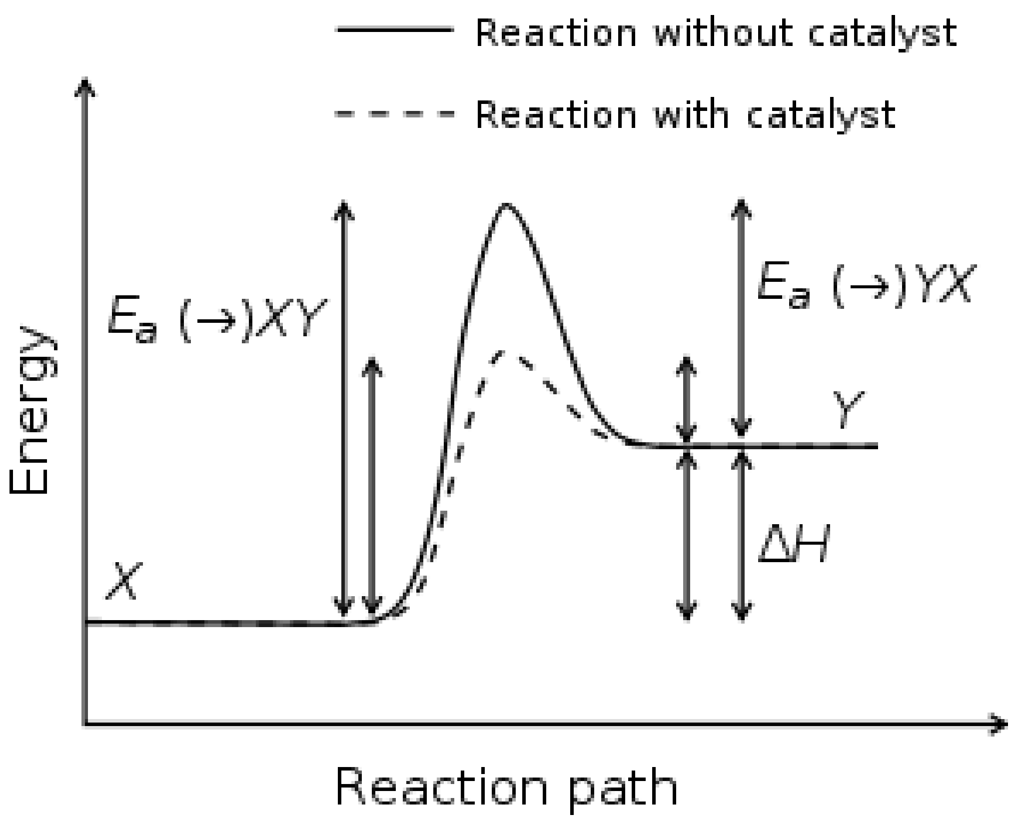
H-CH_2-CH_2-

[Electron Temperature ≈ 25,000 K !]

Hydrogen bond energy ≈ 3 – 4 eV

2. Background

Catalytic vs Microplasma Reforming Reactions



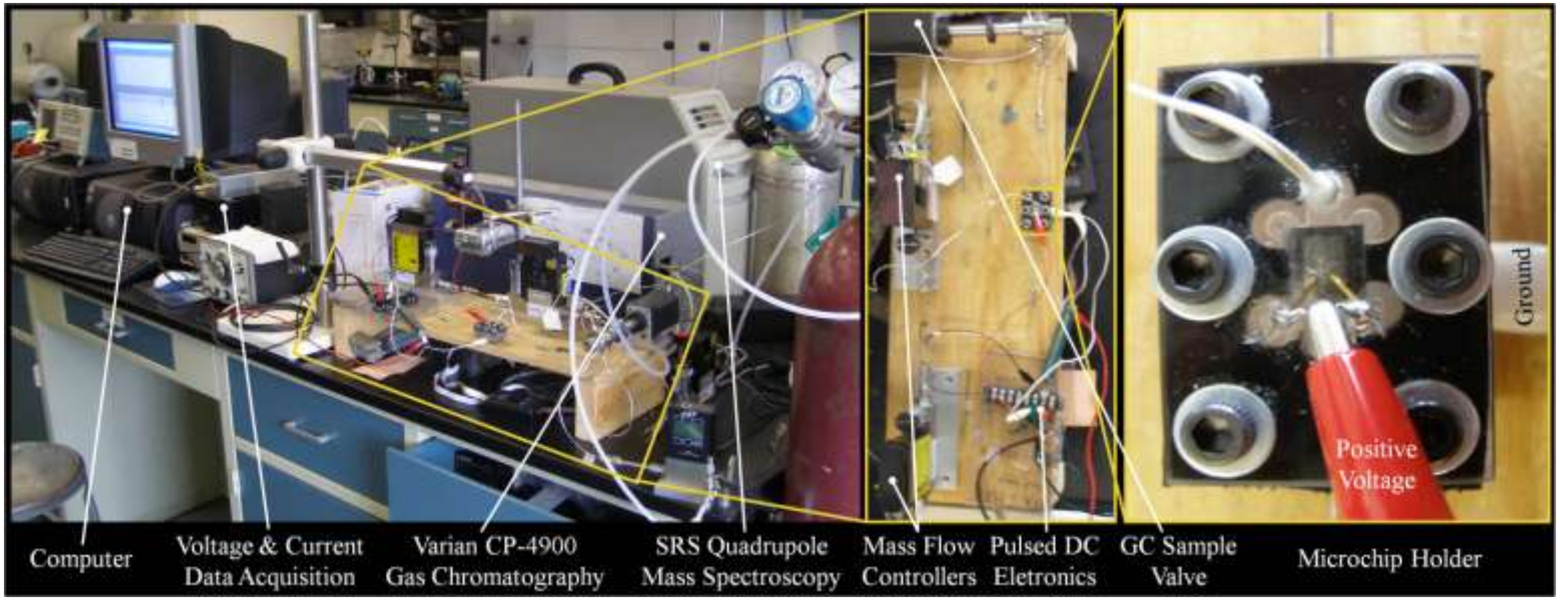
http://en.wikipedia.org/wiki/Activation_energy [4]

Benefits of Microplasma Reaction Environment:

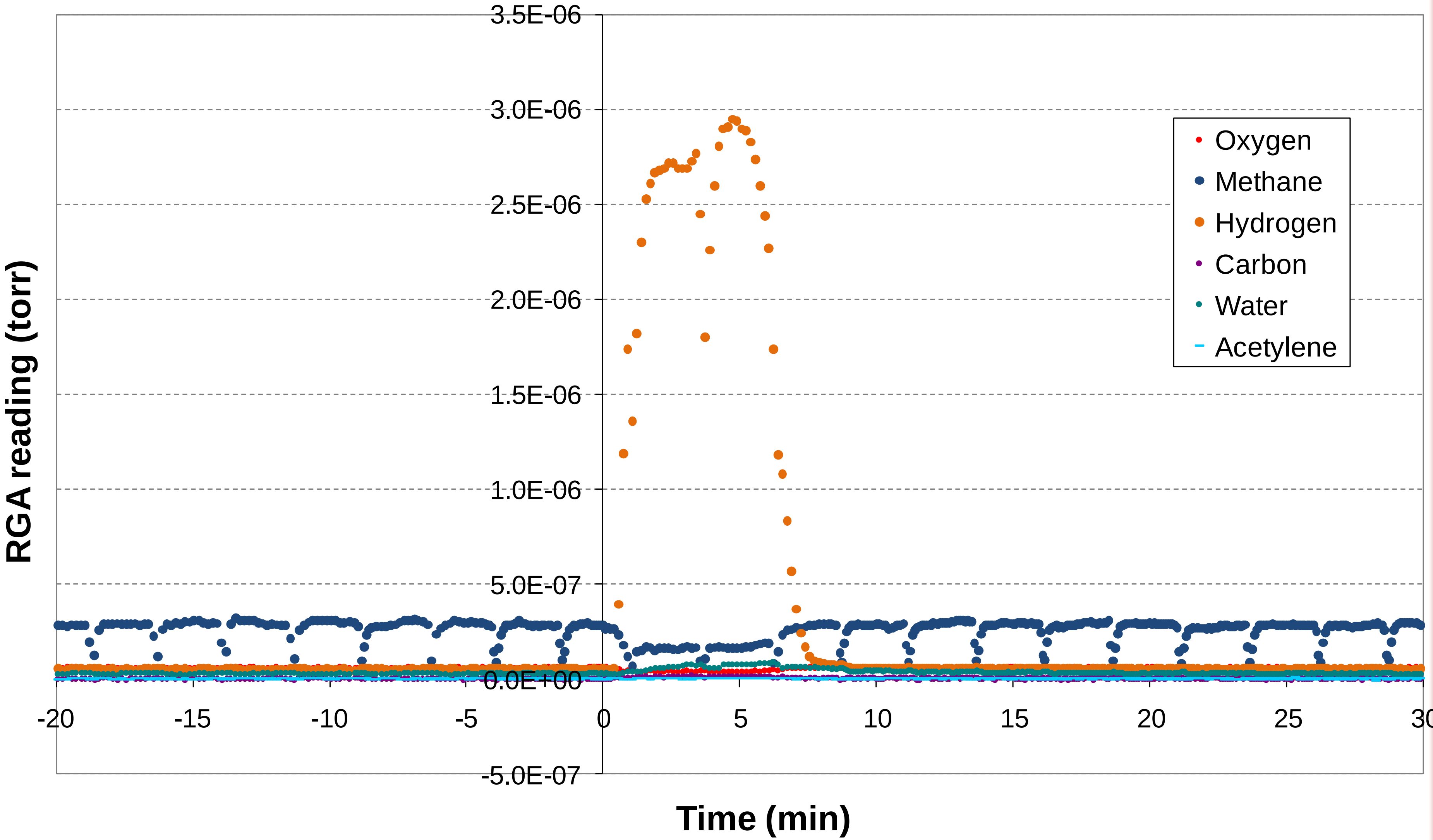
- No catalytic degradation such as coking or catalyst coarsening over time.
- Rapid start up.
- Operation at ambient temperature (reactor material compatibility issues significantly reduced).
- Operation at atmospheric pressure (more energy efficient for microplasmas due to lower breakdown voltages).
- **High electron density ~10^{15} cm^{-3} to facilitate chemical conversion of hydrocarbons.**

DC Power Supply

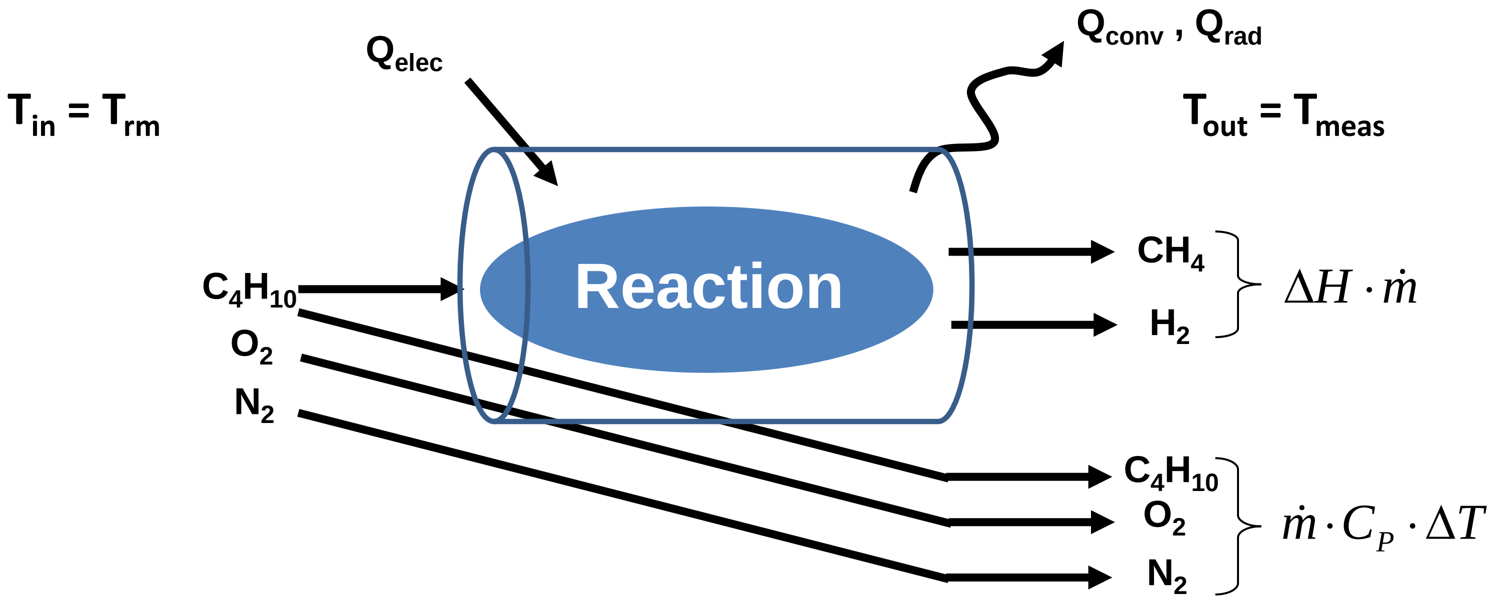
Pulsed DC Power Supply
10-50 kHz



Reactants and Products

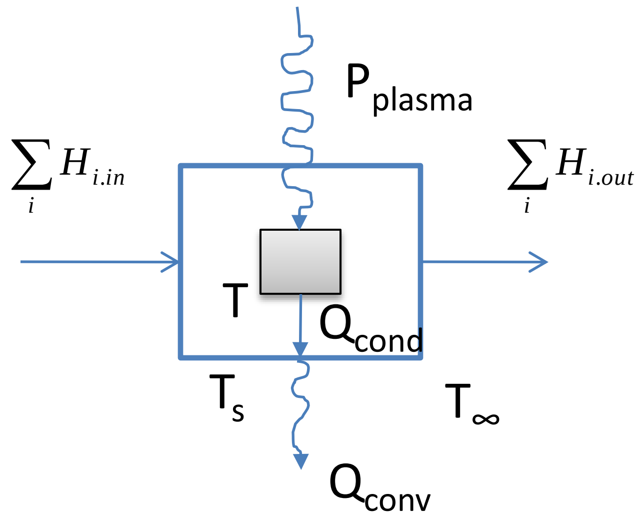


Mass and Energy Balances



$$\left(\sum_i H_i^0 \cdot \dot{m}_i\right)_{in} - \left(\sum_j H_j^{T_{out}} \cdot \dot{m}_j\right)_{out} + I \cdot V - \dot{Q}_{conv} - \dot{Q}_{rad} = \frac{d}{dt}\left(mC_pT\right)_{sys}$$

Energy Balance Approach



$$Q = Q_{cond} = Q_{conv}$$

$$kA\frac{T - T_s}{\Delta x} = hA(T_s - T_\infty)$$

Assume $\Delta H \ll P_{plasma}$, Q

$$\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{sys}}{dt} \neq 0$$

$$\boxed{P_{plasma} + Q = (mC_p)_{sys}\frac{dT}{dt}}$$

With no plasma, gases still flowing:

$$Q = (mC_p)_{sys}\frac{dT}{dt}$$

$$Q = Q(T)$$

Outline

- Perspective: Chemical Engineering Reaction Engineering
- Perspective: Microplasma Reforming Research
- Energy Input: Feedstock Heating Values
- Biomass Conversion: Main Approaches
- Focus on Thermochemical Approach: Gasification
- Plasma Gasification Mechanisms
- Status: Modeling and Simulation
- Status: Process Scaling

Heating Values of Biomass Feeds

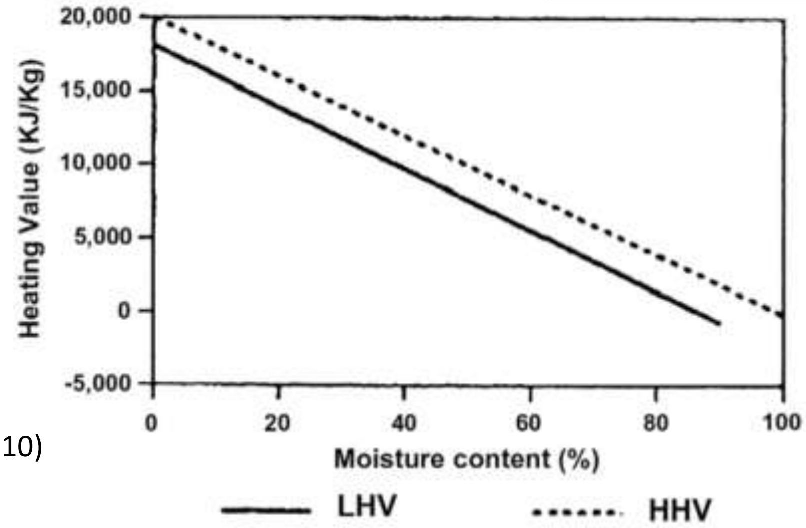
Biomass	Residue yield ($t\,ha^{-1}$)	Heating value ($MJ\,dry\,kg^{-1}$)
Wheat straw	2.97	17.9
Rice straw	4.52	16.8
Almond branches	6.21	18.4
Olive kernels	64.0	18.9
Ptolemais lignite	–	16.9
Forest residue	–	19.5
Hazelnut shell	–	15.43
Safflower seeds	–	23.86
Rapeseed	–	26.7
Cotton seed residue	–	16.9

(Saxena, 2009)

RDF composition and properties.

Proximate analysis (wt.%)		
Moisture	20	
Volatile matters (dry basis)	75.95	
Fixed carbon (dry basis)	10.23	
Ash (dry basis)	13.81	
Ultimate analysis (wt.%)		
C	48.23	
H	6.37	
N	1.22	
Cl	1.13	
S	0.76	
O	28.48	
Ash	13.81	
Heating values		
	Dry	20% Moisture
HHV (MJ/kg)	17.8	14.2
LHV (MJ/kg)	16.3	12.9

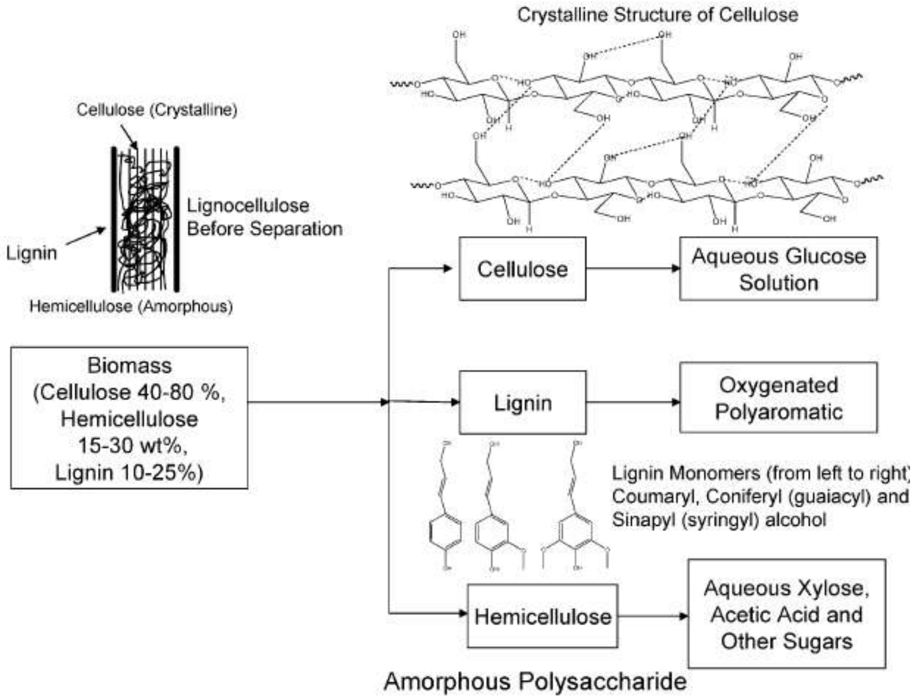
(Minutillo, 2009)



(Zhang, 2010)

Moisture Content is an Issue

Nature of Ligno-Cellulosic Feedstocks

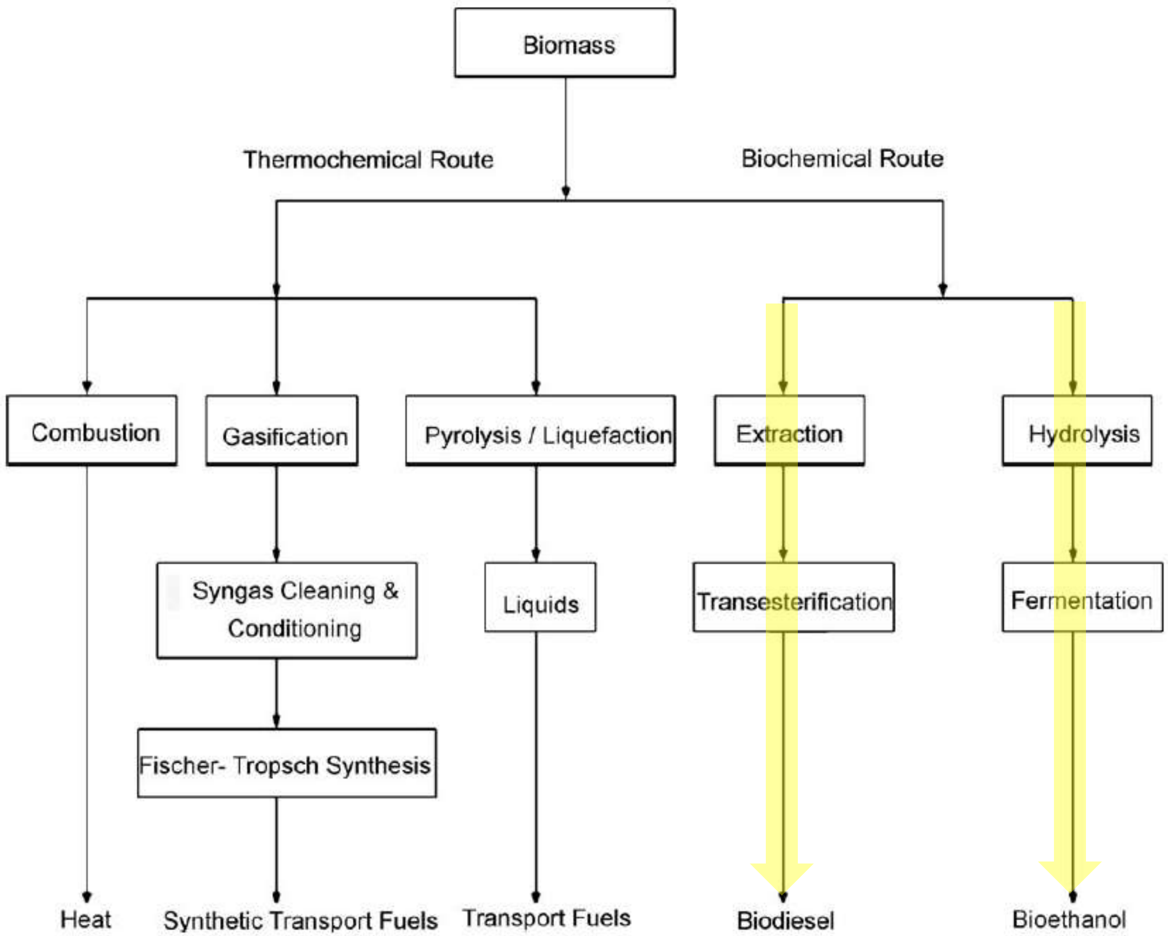


(Huber, 2006)

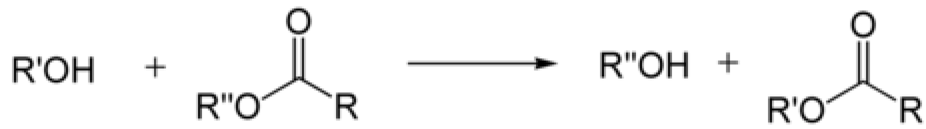
Component	Percent dry weight (%)	Description
Cellulose	40–60	A high-molecular-weight (10^6 or more) linear chain of glucose linked by β-glycosidic linkage. This chain is stable and resistant to chemical attack
Hemicellulose	20–40	Consists of short, highly branched chains of sugars (five-carbon sugars such as D-xylose and L-arabinose, and six-carbon sugars such as D-galactose, D-glucose, and D-mannose) and uronic acid. Lower molecular weight than cellulose. Relatively easy to be hydrolyzed into basic sugars
Lignin	10–25	A biopolymer rich in three-dimensional, highly branched polyphenolic constituents that provide structural integrity to plants. Amorphous with no exact structure. More difficult to be dehydrated than cellulose and hemicellulose

(Zhang, 2010)

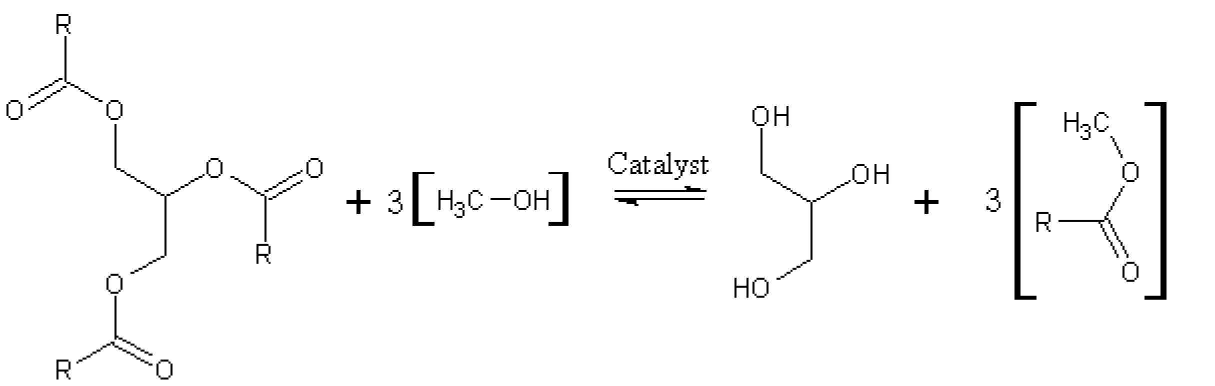
Principal Biomass Conversion Routes



Biochemical: Transesterification



alcohol + ester → different alcohol + different ester



Triglyceride Methanol (3) Glycerol Methyl Esters (3)

Used vegetable oil inside

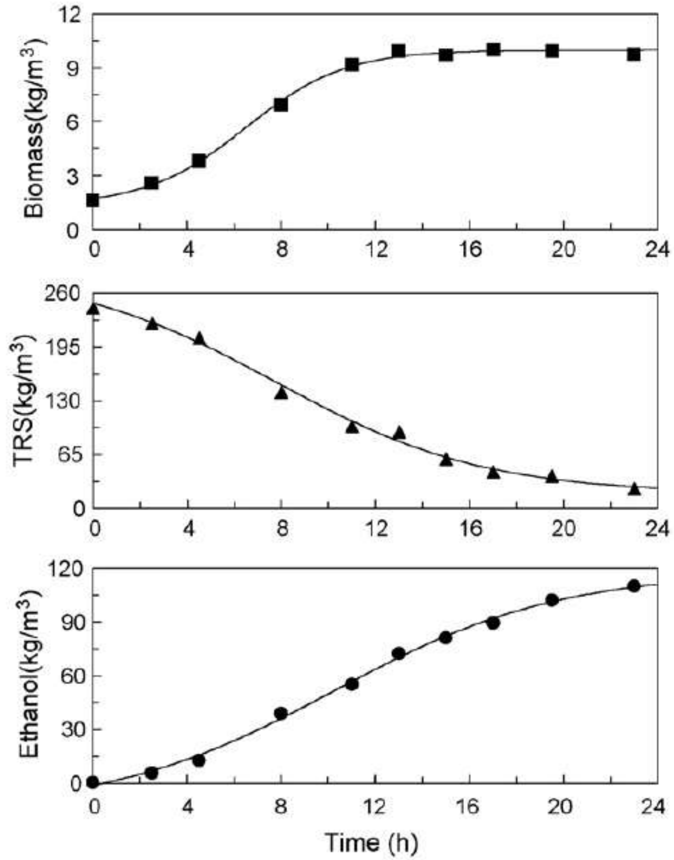
Biochemical: Fermentation

$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$

Sugars directly fermentable

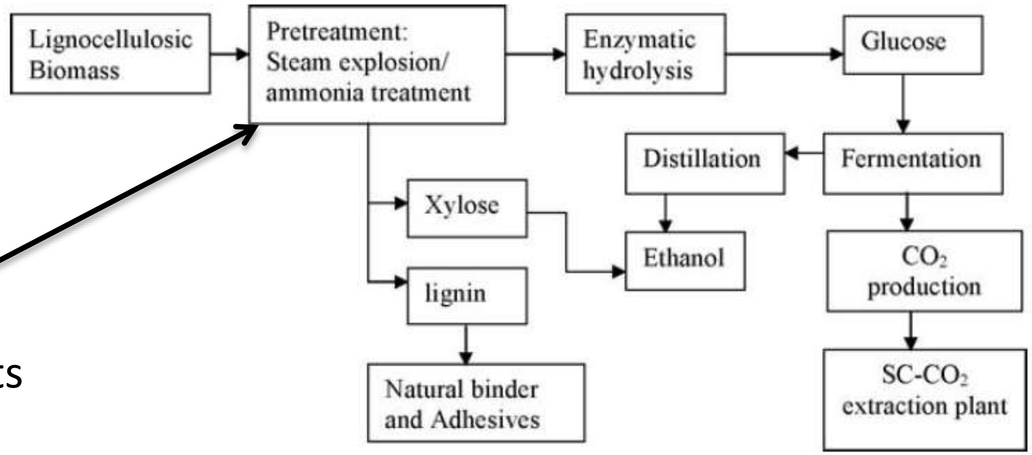
Cellulosic material-pretreatment required

Issue: Consumption of TRS for metabolism and reproduction of organisms



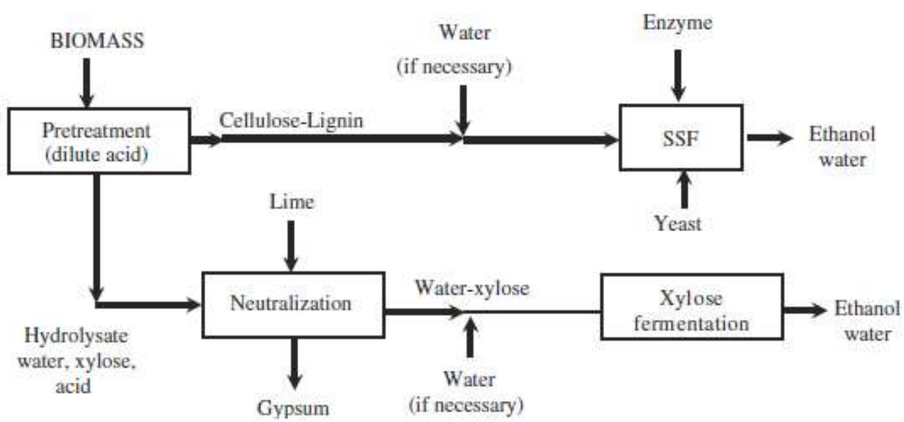
(Rivera, 2007)

Fermentation of Ligno-Cellulosic Biomass



Pretreatments before fermentation

Fig. 13. Conversion of lignocellulosic biomass to ethanol.



Thermophysical Conversion: Gasification

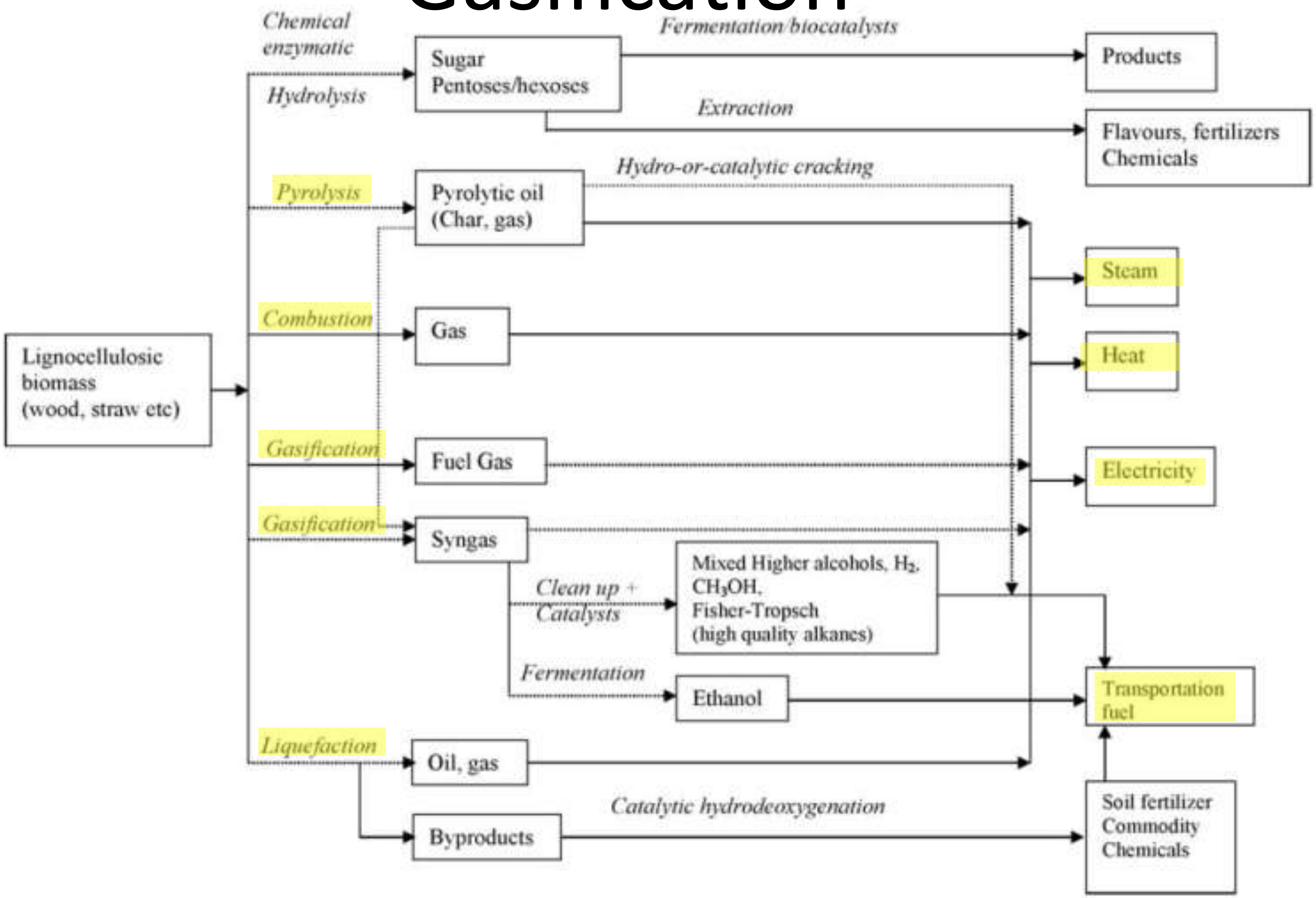


Fig. 16. Forest based and lignocellulosic biorefinery. www.biorefinery.euroview.eu [52].

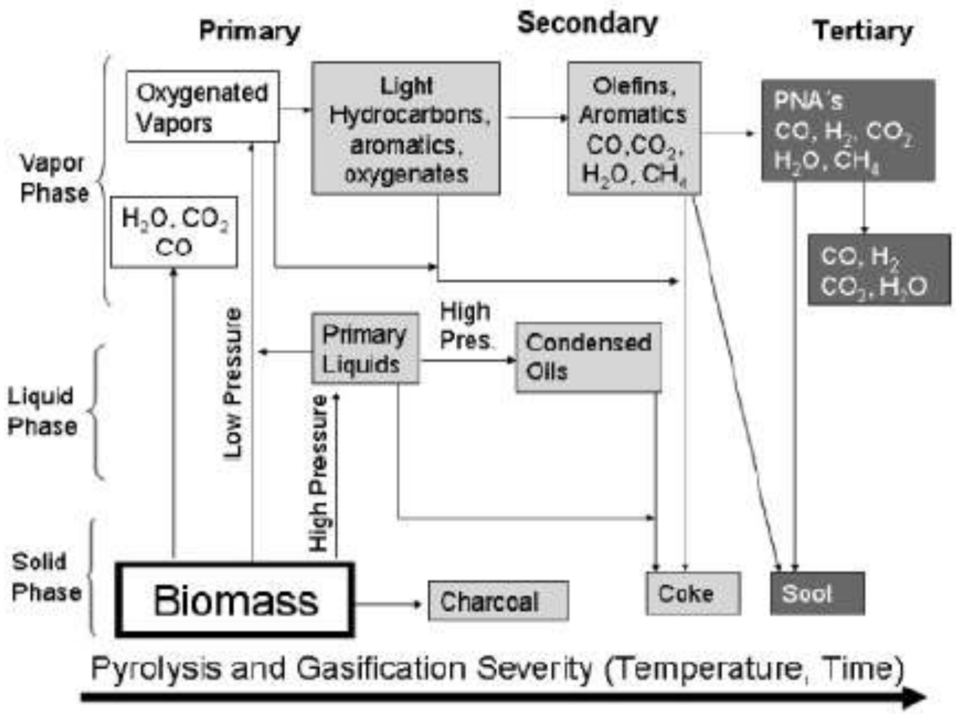
Conventional Gasification

Table 7. Fundamental Reactions and Enthalpy of Selected Cellulose Gasification Reactions[a]

classification	stoichiometry	enthalpy (kJ/g-mol) ref temp 300 K
pyrolysis	$C_6H_{10}O_5 \rightarrow 5CO + 5H_2 + C$	180
	$C_6H_{10}O_5 \rightarrow 5CO + CH_4 + 3H_2$	300
	$C_6H_{10}O_5 \rightarrow 3CO + CO_2 + 2CH_4 + H_2$	−142
partial oxidation	$C_6H_{10}O_5 + {}^1/_2\ O_2 \rightarrow 6CO + 5H_2$	71
	$C_6H_{10}O_5 + O_2 \rightarrow 5CO + CO_2 + 5H_2$	−213
	$C_6H_{10}O_5 + 2O_2 \rightarrow 3CO + 3CO_2 + 5H_2$	−778
steam gasification	$C_6H_{10}O_5 + H_2O \rightarrow 6CO + 6H_2$	310
	$C_6H_{10}O_5 + 3H_2O \rightarrow 4CO + 2CO_2 + 8H_2$	230
	$C_6H_{10}O_5 + 7H_2O \rightarrow 6CO_2 + 12H_2$	64

[a] Adapted from Klass.[2]

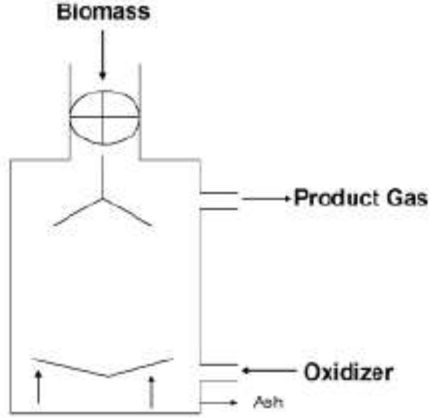
Thermochemical: Gasification



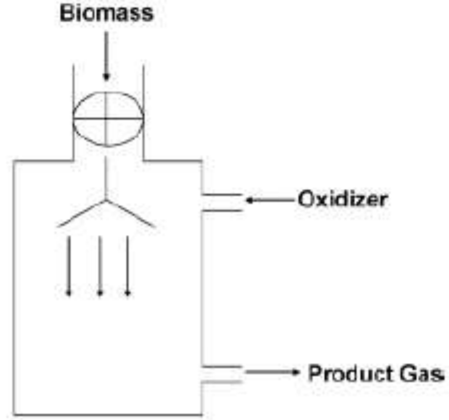
(Huber, 2006)

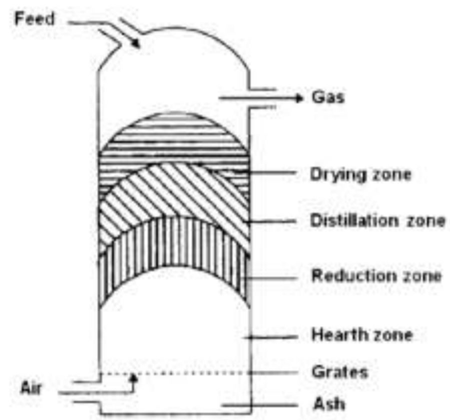
Conventional Gasifiers

A) Updraft Gasifier

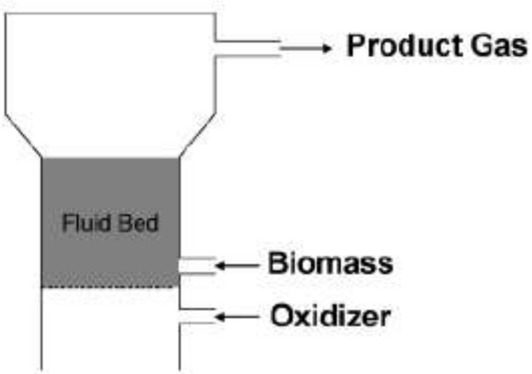


B) Downdraft Gasifier





C) Fluid-Bed Gasifier



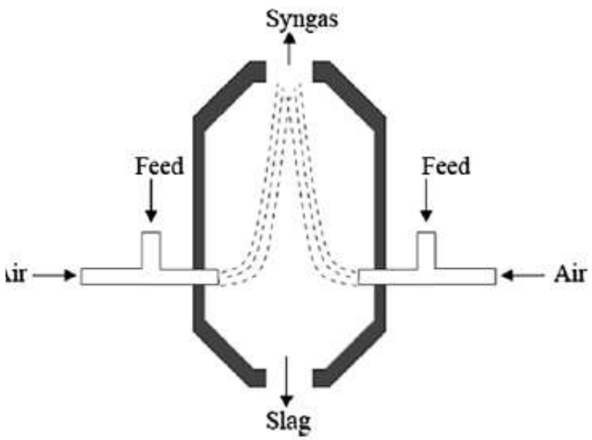


Fig. 7. Configuration of the entrained flow gasifier [48].

Plasma Torch and Gasifier

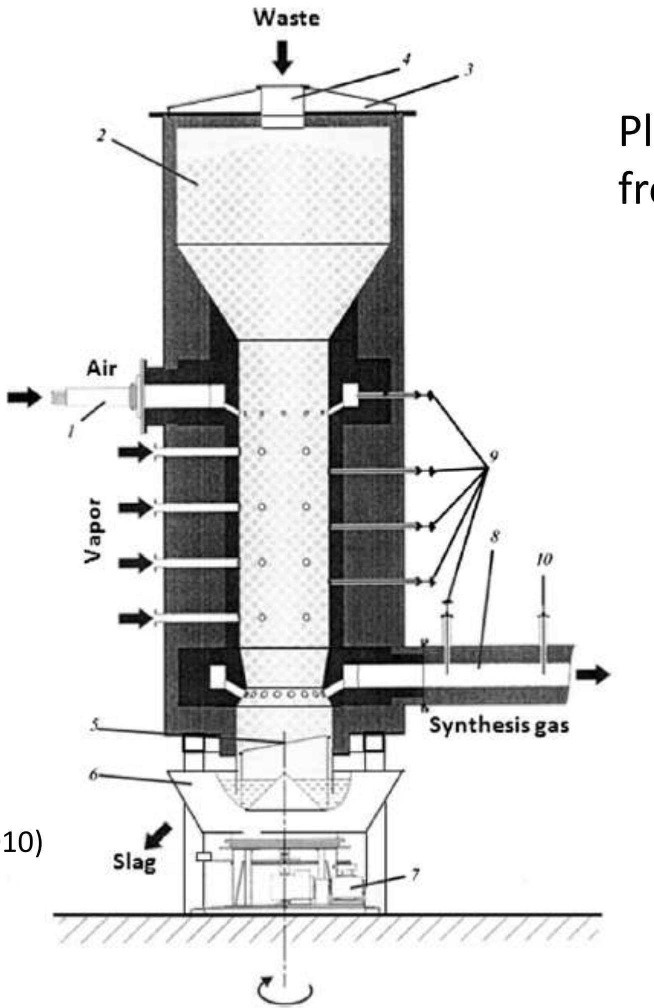
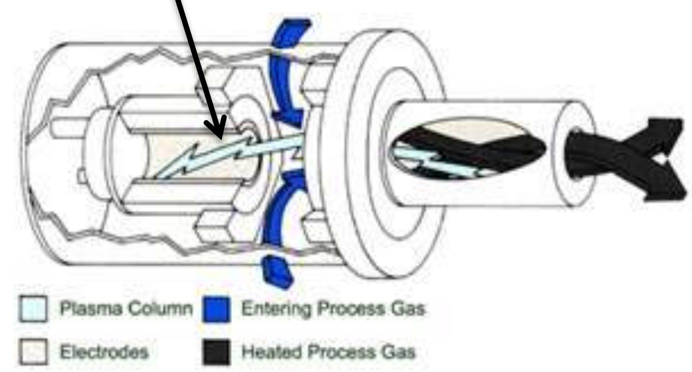


Fig. 9. Configuration of a shaft-type plasma gasifier reactor. (1) plasma generator, (2) bin with waste, (3) cover, (4) charging batch, (5) fire grate, (6) bath with water for quenching the slag, (7) fire grate rotation drive, (8) gas duct, (9) temperature sensors and (10) gas sampling [84].

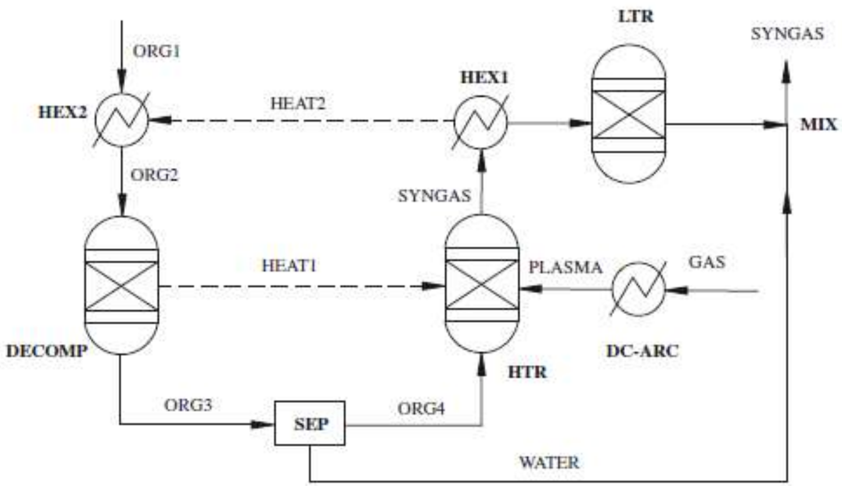
(Zhang, 2010)

Plasma generation is "remote" from fed species



(recoveredenergy.com)

Plasma Gasification, Model and Simulation



Aspen Plus Model

$$\eta_{PG} = \frac{\dot{m}_{Syngas} \cdot LHV_{Syngas}}{\dot{m}_{RDF} \cdot LHV_{RDF} + (W_{Torch} + W_{ASU})/\eta_{el}}$$

Compared simulated cases with enhanced O_2

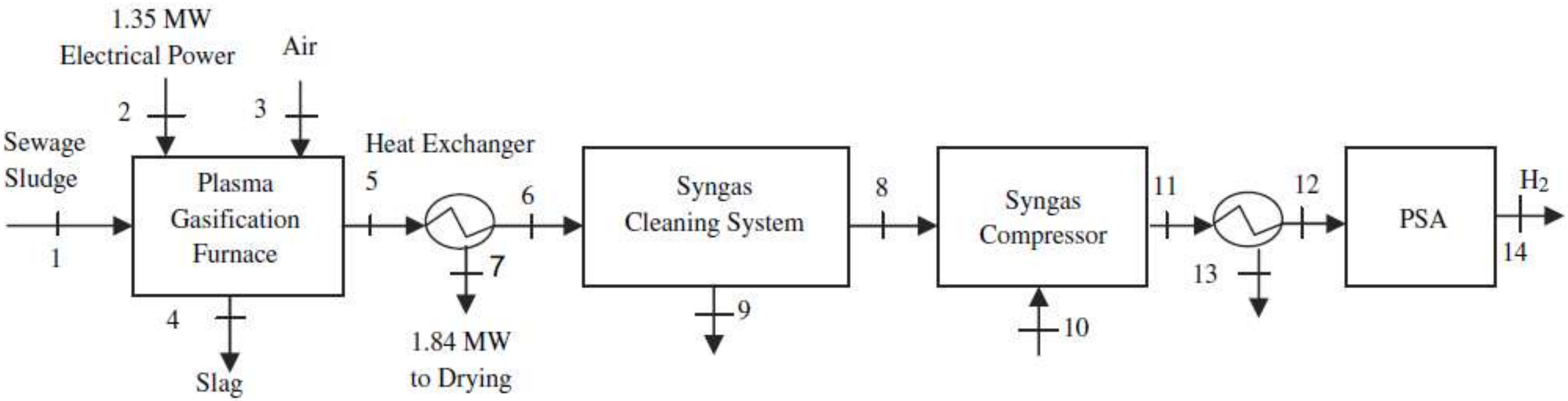
Gasifier + ASU tandem cases compared

ASU = Air Separation Unit

(Minutillo, 2009)

	Case A	Case B	Case C
Syngas, LHV (MW)	15.97	15.48	14.74
Torch power consumption, W_{Torch} (MW)	4.26	3.44	2.75
ASU power consumption, W_{ASU} (MW)	–	0.157	0.195
η_{PG} (%)	63.6	66.7	69.1
Syngas composition (mol%)			
H_2	21.04	31.49	28.65
CO	33.79	38.73	37.37
CH_4	5.97	–	–
CO_2	–	0.42	1.41
H_2O	11.68	12.50	14.91
N_2	26.97	16.32	17.12
HCl	0.32	0.31	0.31
H_2S	0.22	0.22	0.22
COS	0.02	0.01	0.01
HHV (MJ/kg)	10.50	11.06	10.13
LHV (MJ/kg)	9.55	10.10	9.20

Process Analysis



(Kalinici, 2011)

Exergy = available energy

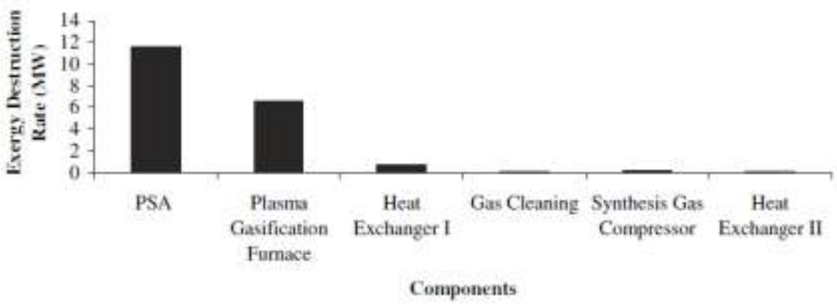


Fig. 2 – Exergy destruction rates of components.

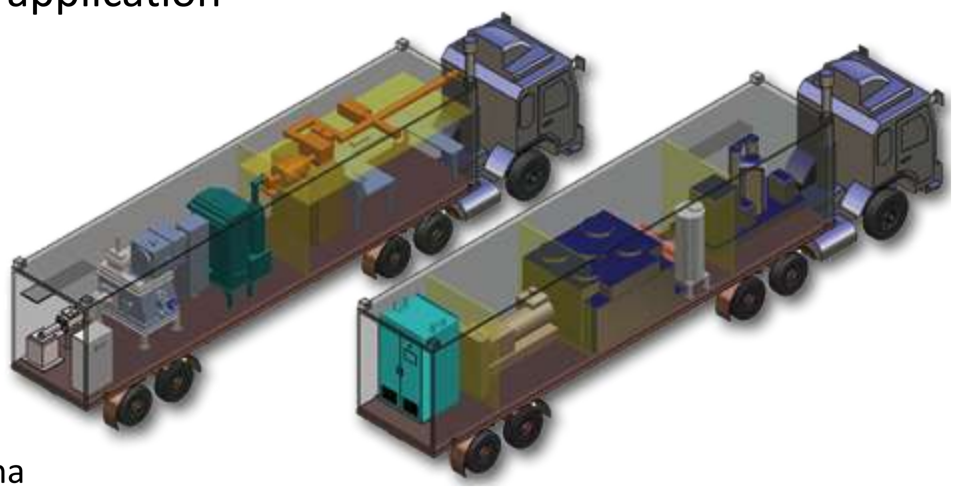
Scaling of Plasma Gasification

Based on Minutillo paper (15 MW plasma sources/ 471,000 kg/day)

Torch capacity to process 1 ton/day in small scale system (Allmon):

=29 kW

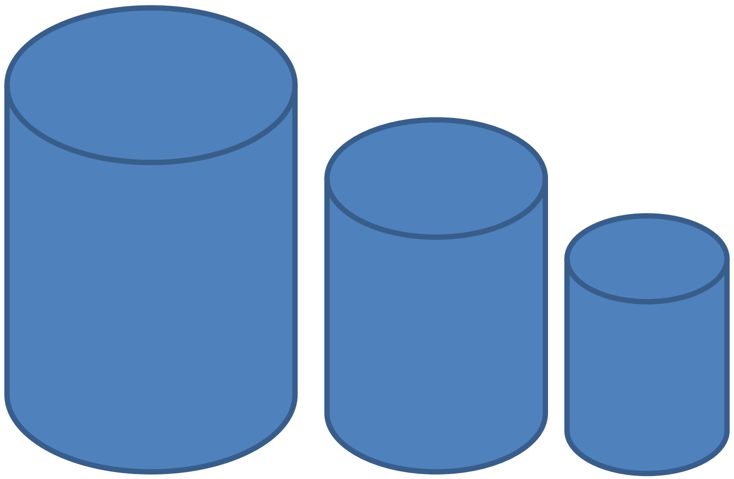
Smaller sources exist, e.g., sources for ICP mass spectrometer ionizers, but very different application

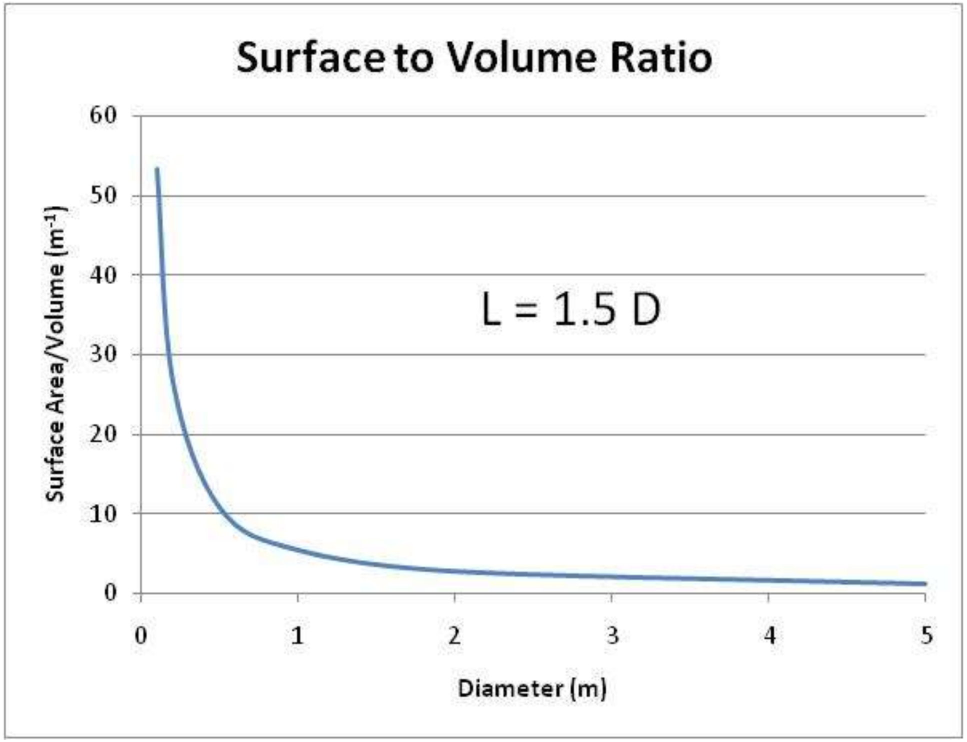


Arc Master I Portable Plasma Gasification System, CBP

Scaling Issues

Constant L/D Ratio





SA/V Increasing →

Heat Loss

Surface Reaction-quenching

Energy Efficiency

Scaling Continued

- Control of residence time in plasma heated zone is function of several variables (falling rate, fluidization, size of plasma plume, etc.); difficult to maintain t in smaller geometry.
- Continuous feeding (vs. batch) will be more difficult for same reasons.

Conclusions/Recommendations

- Plasma gasification is clearly viable
- The case for waste destruction is strong
- Self sustaining or net energy production depends on the waste
- Biomass feedstock processing is attractive but seems like a (local) logistical nightmare (for mobile DoD application)
- Downscaling to 1 ton/day may not be viable; research needed

Plasma Gasification:
Research – Challenges and Needs

Greg Jackson

Dept. of Mechanical Engineering

University of Maryland

ARL Power Sources Focus Group on Plasma Gasification

September 28, 2011

Academic Research Perspective on Plasma Gasification

- **What are the principal "unknowns" with respect to plasma gasification? Can plasma gasification be modeled/simulated with high fidelity?**
  - *Questions about biomass/waste gasification itself*
  - *Questions about plasmas*
- **What are the scaling limits to low and high volume processing?**
- **How "green" is plasma gasification? How does it compare with other gasification technologies or low temperature processes for converting biomass into gas or liquid fuels?**
- **What research is needed to improve plasma gasification, in particular with respect to compact, small-scale processing of waste and agricultural residue for synthesis gas production?**

Questions of Biomass Gasification of Kinetics

- **Modeling actual solids gasification (in oxidizing environment – O_2 and/or H_2O, CO_2)**
  - *Lumped parameter analysis using major component families for gasification kinetics*
    - Cellulose, hemi-cellulose, and lignin
    - Char
  - *Lumped kinetics show sensitivity to heating rates*

$$\frac{d\alpha_l}{dt} = A_l \exp\left(-\frac{E_{act,l}}{RT}\right)(1-\alpha_l)^n$$

$$\alpha_l = \left(\frac{m_{l,init} - m_l}{m_{l,init} - m_{ash}}\right)$$

  - *Gaseous products not captured in kinetic models but rather measured*
  - *High-temperature (such as plasma gasification) may be approximated by equilibrium products*
    - importance of quantifying solid residue

Questions of Biomass Gasification of Kinetics

- **Range of kinetic parameters for fast gasification in air from some reviews but consensus for fast pyrolysis parameters remains unclear.**

$$\frac{d\alpha_l}{dt} = A_l \exp\left(-\frac{E_{act,l}}{RT}\right)\left(1-\alpha_l\right)^n$$

$$\alpha_l = \left(\frac{m_{l,init} - m_l}{m_{l,init} - m_{ash}}\right)$$

	Wood mass	E_{act} (kJ/mol)	n	$\log_{10}(A)$ (A in min^{-1})
Cellulose (Antal et al. 1998)	50-60%	175 – 210	1.0	12.8 – 16.0
Hemicellulose (Ranzi et al. 2008)	15-30%	110 – 140	1.0	11.3 – 11.9
Lignin (Jiang et al. 2010)	10-30%	130 – 175	1.0 – 1.5	10.5 – 13.0
Char (di Blasi 2009)	N/A	120 – 190	0.5 – 2.0	9.0 – 12.5

Questions of Biomass Gasification of Kinetics

- **Gasification (fast pyrolysis) in non-oxidative environment at high-temperatures (600 – 1000 °C) produces significant amount of condensable species (Rutberg et al. 2011).**
  - Fast pyrolysis must be aided by external heating either through hot “ablative” surfaces, or externally or internally heated fluidized beds
- **Plasmas may also provide heating but the high temperatures basically eliminate the formation of condensibles.**

Kinetics Modeling for Biomass Plasma Gasification

- **Model for gasification in CFD must be adequately detailed to capture expansion for fluid flows and rates of gasification for interphase heat / mass transfer**

- **Conventional model for cellulose (Broido-Shafizadeh)**

Cellulose $\xrightarrow{k_1}$ Activated Cellulose

Activated Cellulose $\xrightarrow{k_2}$ Tar and small HC's

Activated Cellulose $\xrightarrow{k_3}$ Char C(s) and gases (CH_4, CO, CO_2, H_2, and H_2O)

- **Alternative model developed for plasma gasification (UMD/NUWC-Carderock)**

Cellulose $\xrightarrow{k_{1'}}$ Activated Cellulose

Activated Cellulose $\xrightarrow{k_{2'}}$ Gaseous monomer $\xrightarrow{k_{5'}}$ Tar and small HC's

Activated Cellulose $\xrightarrow{k_{3'}}$ Char C(s) and gases (CH_4, CO, CO_2, H_2, and H_2O)

Gaseous monomer $\overset{k_{4'}}{\longleftrightarrow}$ Char C(s) and gases (CH_4, CO, CO_2, H_2, and H_2O)

Kinetics for Cellulose Gasification in Plasma

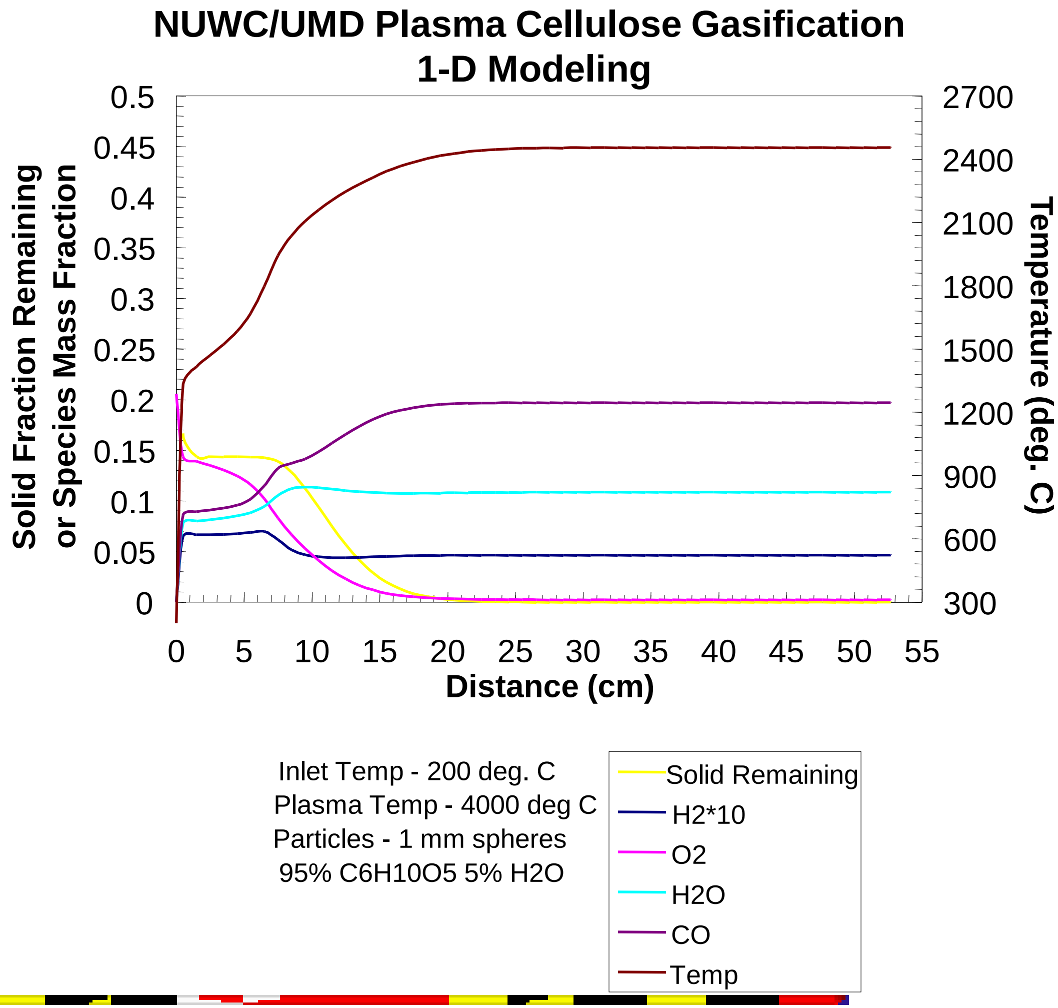
- **Kinetic mechanism for cellulose pyrolysis and gasification**

R1) gasification reaction	$C_6H_{10}O_5(s) \rightarrow C_6H_{10}O_5(g)$	E_{act} = 138 kJ/gmol
R2) char formation	$C_6H_{10}O_5(s) \rightarrow 4C(s)+2CO+2H_2+3H_2O$	E_{act} = 115 kJ/gmol
R3) char agglomeration	$C(s)+C_6H_{10}O_5(g) \rightarrow 5C(s)+2CO+2H_2+3H_2O$	
R4) char oxidation	$2C(s)+O_2(g) \rightarrow 2CO(g)$	E_{act} = 173 kJ/gmol
R5) char oxidation	$2C(s)+H_2O\,(g) \rightarrow 2CO(g)$	E_{act} = 147 kJ/gmol

- **Kinetic parameters guided by experimental measurements on model cellulose species**
  - *Similar steps can be done for other characteristic biomass materials*
  - *Lack of knowledge on role of alkaline metals on reaction processes/kinetics.*
- **These are coupled to a $C_6H_{10}O_5(g)$ decomposition reaction and an appropriately detailed C_1-C_2/H/O mechanism such as GRI-mechanism or better some reduced mechanism.**
- **Example of complex mechanism in plasma gasification design (Fourcault et al. 2010)**

Using Gasification Kinetic Model in System

- **Rapid gasification in plasma suggest need for models to optimize design for minimal footprint/heat loss and maximum system efficiency.**



Question of Modeling Plasmas

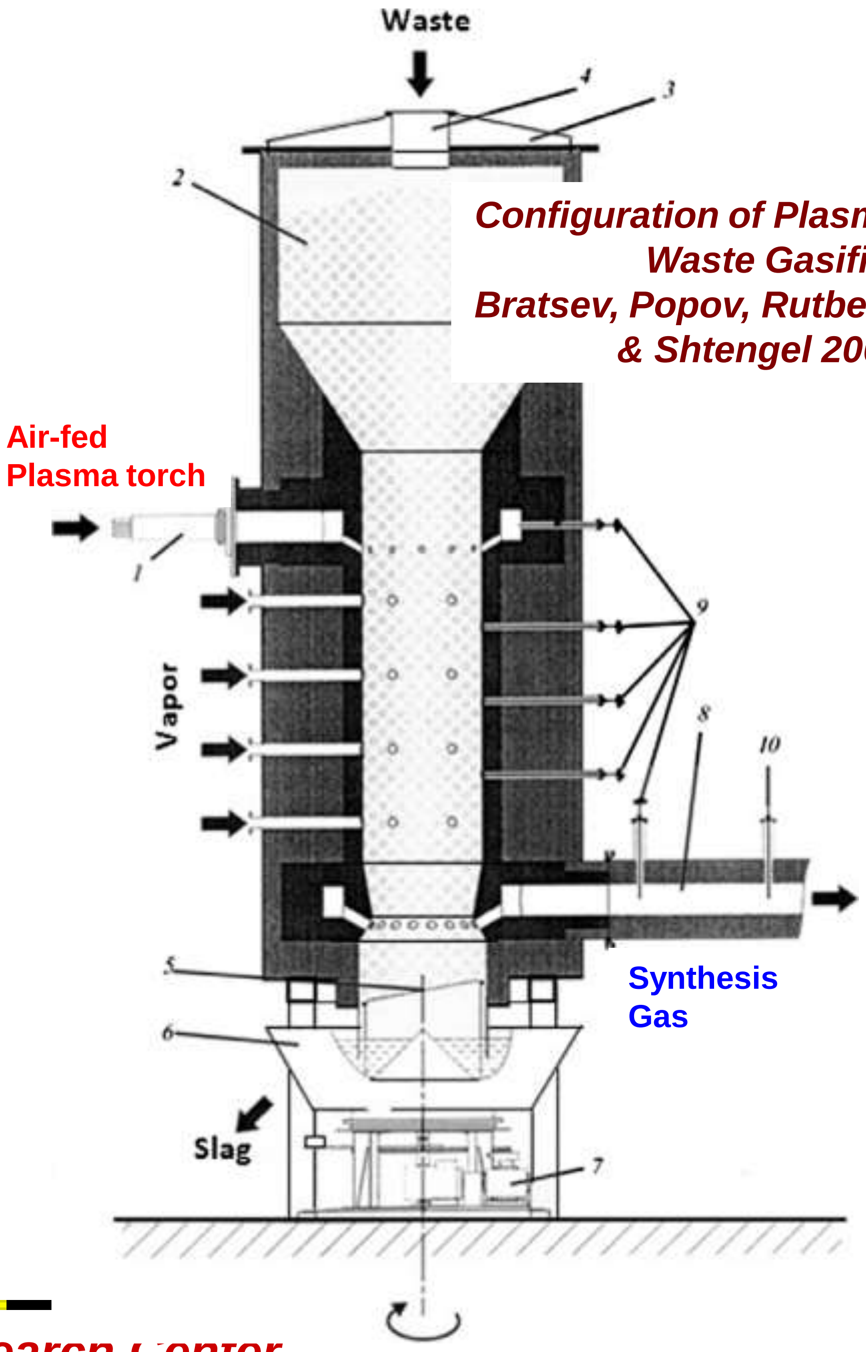
- **Modeling the plasma energy input to the gas**
  - Efficiency of energy transfer to the gas is the key parameter
  - RF capacitively coupled plasmas have been reported to deliver 90+% of energy to the gas although this may drop in smaller-scale applications.
  - Uncertainties can lead to overdesign of plasma power and reduced electrode lives (<< 1000 hours).

Question of Modeling Plasmas

- **From a kinetics standpoint, plasma gasification (oxidative or pyrolysis) tends to simplify reactor modeling effort due to the high-temperatures involved.**
  - Almost complete elimination of condensable in product stream
  - Exception: Question about the role of increased free radicals in the plasma.
- **From a heat and mass transfer (reactor design standpoint), the plasma can complicate the modeling effort.**
  - Plasma is primarily a heat source, but it does result in radical production
    - Reliance on combustion chemistry adequate for predicting behavior.
  - Very large temperature and species gradients impact the local rate of gasification and the residence time of particulate matter in high-temperature regions.
    - Particular challenge for more endothermic reaction processes.
  - Uncertainties can lead to overdesign of plasma power and reduced electrode lives (<< 1000 hours).

Questions of Scaling

- Plasma heating due to electron bombardment should not be significantly impacted by smaller system.
- Heat loss from plasma due to radiation, conduction, and heat of surface enhanced recombination to walls reactions could be significant and reduce plasma heating efficiencies << 90%.
- Effective solid entrainment energy a challenge.
- Staged vapor injection for endothermic gasification limited.



Configuration of Plasma Waste Gasifier Bratsev, Popov, Rutberg & Shtengel 2006

How Green is Plasma Gasification?

- **Different studies make claims based on simple assumed power plant efficiencies and plasma efficiencies.**
  - Rutberg, Bratsev et al. 2011
  - Fourcault, Marias, and Michon 2010
- **Fourcault et al. analysis estimates a second-law efficiency range of 60-70% for realistic operating conditions (based on moisture content and O_2 content in oxidizer) using plasma + fuel input**
  - Used 100% efficiency of plasma.
- **With assumed 85-90% efficiency of plasma heating, overall efficiency drops to 50-60% based on plasma + fuel input.**
- **If syngas is used for fuel in gensets for military applications (< 100 kW) efficiencies will range from 25-40+% based on engine size, leaving overall efficiency (based on fuel input only) in the range of 15-30% without including plasma power requirements.**
  - SOFCs or other fuel cell technology may increase those number in future.
- **Plasma power requirements range from 25-35% of heating value according to Fourcault et al but are reduced by dry feeds and increased O in feed.**

Research Needs to Improve Plasma Gasification for Energy and Fuel Production

- **Improved models of plasma heating process for efficient torch design over a range of operating conditions and length scales.**
- **Developing improved electrode surfaces for longer-life of electrodes.**
- **Better high-temperature kinetics of biomass to develop strategies for minimizing char yields.**
- **Developing adaptive control strategies coupled to system observables for plasma gasification to learn fuel properties and minimize plasma power requirements.**
- **CFD models remain as a limited design tool and improved multi-phase flow reactor modeling can be brought to bear on this problem.**
- **Look at low-temperature plasmas for bio-oil production – efforts active in Asia.**

SOLENA GROUP

Introduction to

Zero Emissions Bio-Energy

Dennis F. Miller, Vice President/Science Advisor

Unique Investment Opportunity

Renewables

Clean Energy

Solution for global energy demand, global waste crisis, and global policy mandates

SOLENA GROUP

Market Demand & Policy - Favorable Driver

- Global Warming & Climate Change
  - Fossil Fuel Identified as a culprit
  - Hydrologic changes & severe conditions
  - Public awareness
- Kyoto Protocol & European mandates/ETS
  - EU Directive for 20% renewable energy by 2020
  - Restrictions on landfills and incineration
  - ETS Phase 2 – 2006 w/ 22B Euros

US Energy Policies Changing

  - 28 States with RPS
  - RECs and Carbon Trading Program underway

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Dynamics are Changing in the U.S. Market

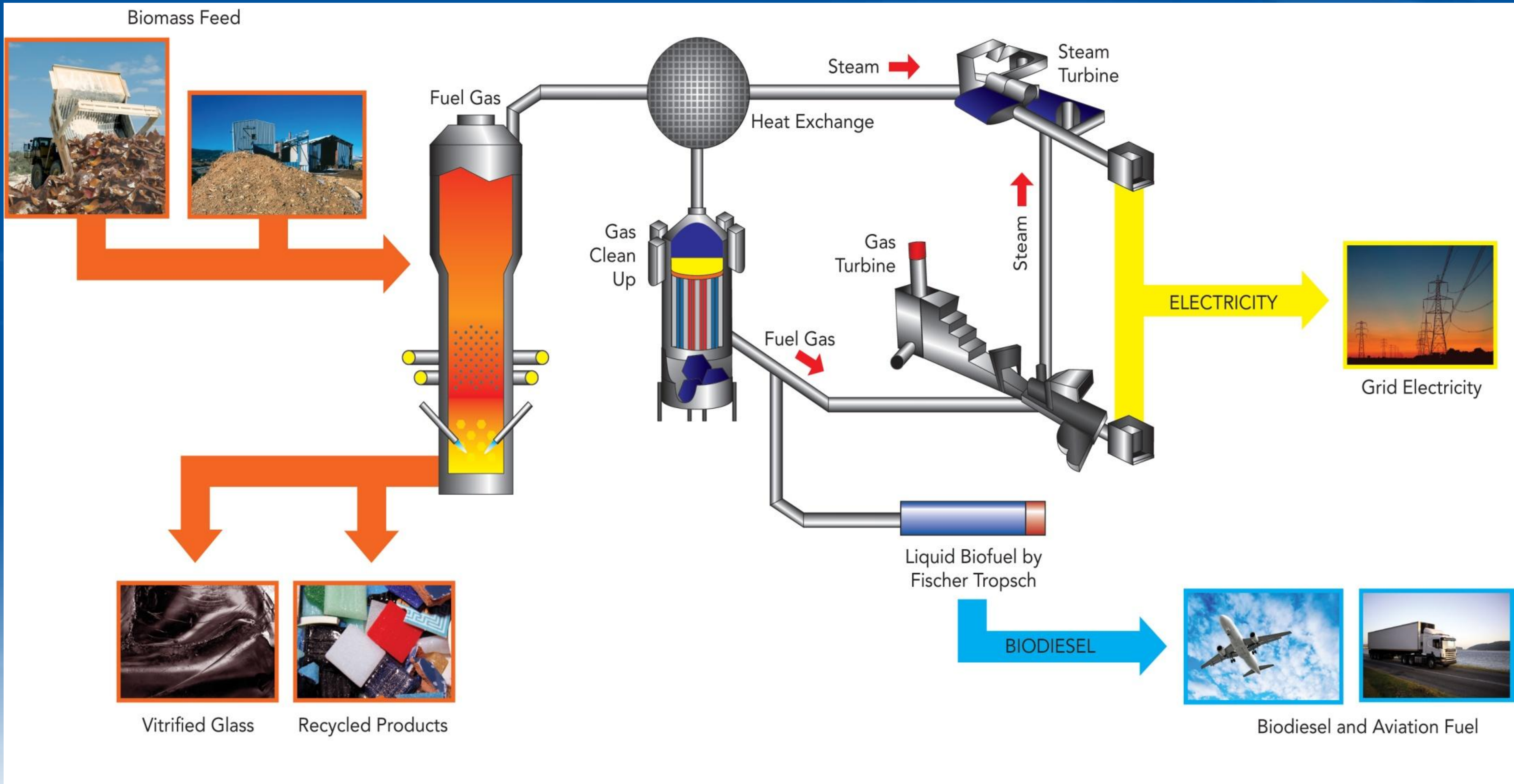
- Legislative trends
  - Twenty eight States have initiated RPS
  - Specific demand for biomass based RE
  - Incentives for Bio-fuels
- Credit trading systems exist for emissions and possibly for CO2 in the near future
- Increasing demand for distributed energy and “closed loop ” solutions
- EPA favorable regulations for Gasification
- Immediate Demand for Bio fuels

SOLENA GROUP

Solena's Turn-Key Solution Meets Market Need

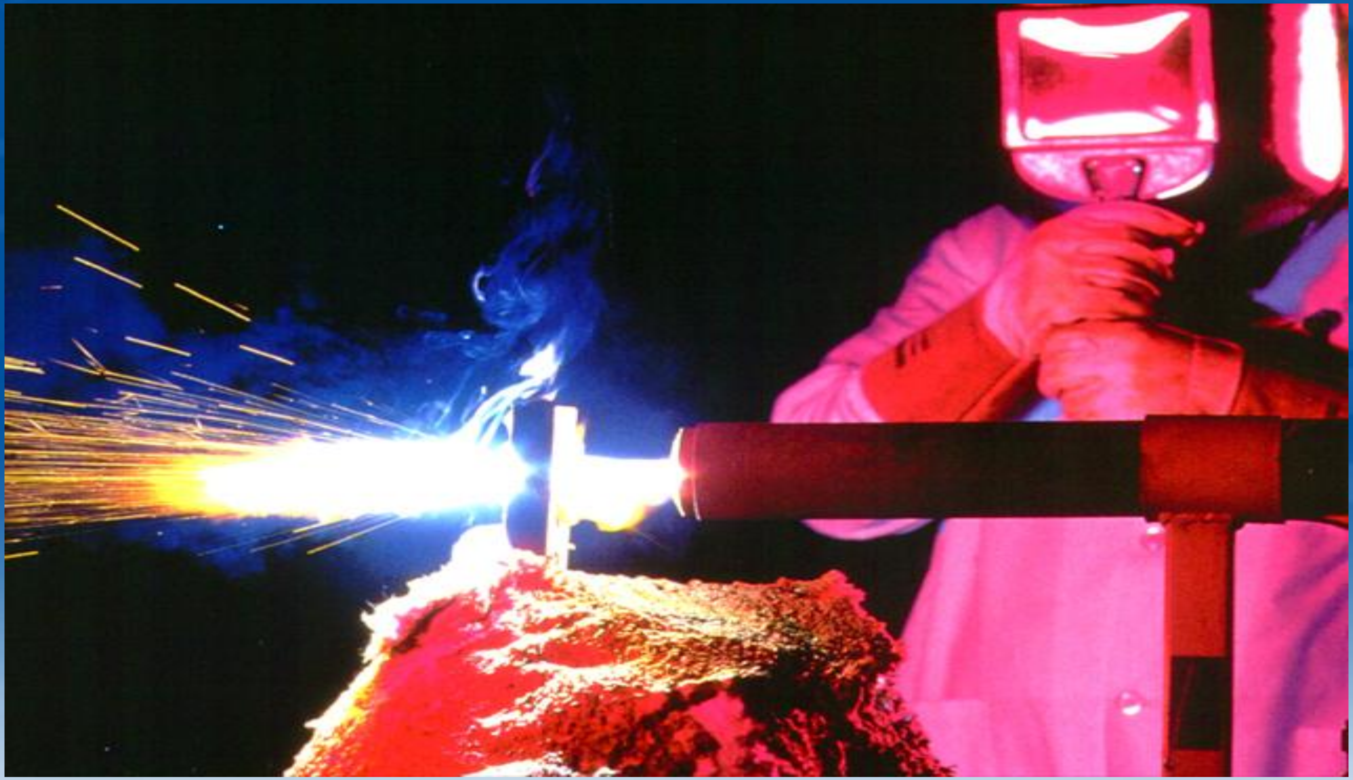
Solena Zero Emission Bio-Energy Production Program

Solena Process Flow Diagram



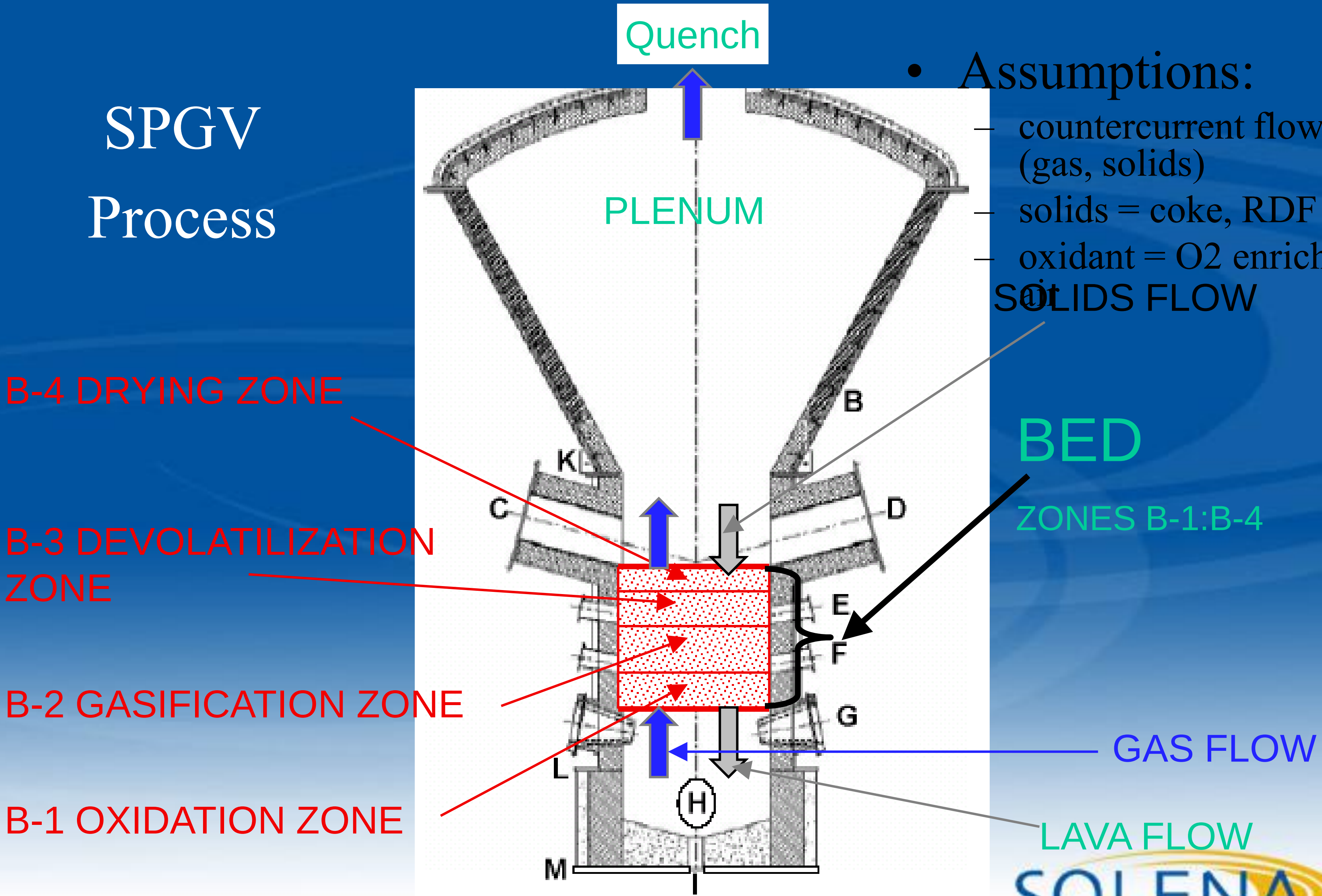
Solena Plasma Gasification Technology

Plasma: A Proven Technology



SPGV Process

- Assumptions:
  - countercurrent flow (gas, solids)
  - solids = coke, RDF
  - oxidant = O2 enriched air



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Flexible Fuel Sources

PLASMA GASIFICATION REACTOR

Feed
20 Deg. C
13250 Kg/hr

Natural Gas
0 Kg/hr
0 Nm3/hr

Coke (thermal)
107 Kg/hr

Flux - SiO2
0 Kg/hr

Flux - CaO
70 Kg/hr

FeSi
0

FeMn
0 Kg/hr

SiC
0 Kg/hr

Coke Breeze (Sol. C)
0 Kg/hr

Air
500 Deg. C
1301 Nm3/hr
1674 Kg/hr

Oxygen Enrichment
3496 Nm3/hr
4829 Kg/hr

Electricity (Plasma)
1892 KWe
1608 KWt

Electricity (Auxiliary)
331 KWe

PGR Air Ratio
0.02

Offgas
1700 Deg. C
26136 Nm3/hr (gas only)
19735 Kg/hr
11.89 meters/sec

	Wt %	Vol % (gas only)	Kg/hr
CO	70.36%	42.53%	13885
CO2	11.06%	4.25%	2182
O2	0.00%	0.00%	0
N2	8.60%	5.20%	1698
H2	5.35%	45.29%	1056
C2H4	4.24%	2.56%	836
CdO	0.00%		0
ZnO	0.06%		12
PbO	0.00%		0
HCl	0.10%	0.05%	19
H2S	0.23%	0.11%	45
H2O	0.01%	0.01%	2
Total	100.00%	100.00%	19735

Power Generation Option

OffgasDelta H = 8.52E+07 Kcal/hr
Blast Recuperator = 1.50E+05 Kcal/hr
Available Delta H = 8.50E+07 Kcal/hr
Cycle Efficiency @ 45.00%
Electricity Production 44.49 MWe
MW = 16.91 (gas species only)
CO/CO2 = 10.00 (by volume)
HHV = 3258 Kcal/Nm3 (incl. sensible heat)
HHV = 2942 Kcal/Nm3 (without sensible heat)
HHV = 3899 Kcal/Kg (without sensible heat)
LHV = 2718 Kcal/Nm3 (without sensible heat)
LHV = 3601 Kcal/Kg (without sensible heat)

Liq. Metal
0 Kg/hr

Ni	97.9995%
Mo	0.0000%
V	0.0000%
Ti	0.0000%
Mn	0.0000%
Cu	0.0000%
Cr	0.0000%
Fe	0.0005%
C	2.0000%
Si	0.0000%
Total	100.00%

Slag
194 Kg/hr

CdO	0.00%
MgO	0.08%
MnO	0.00%
NiO	0.00%
MoO2	0.00%
V2O5	0.00%
TiO2	0.00%
CuO	0.34%
Cr2O3	0.48%
Al2O3	38.89%
SiO2	8.24%
FexOy	9.57%
ZnO	0.00%
PbO	0.00%
CaO	36.23%
CaCl2	0.00%
CaSO4	0.00%
SnO	0.00%
Na2O	6.10%
Inert	0.00%
Total	99.93%

$$\text{Slag Basicity} = \frac{CaO + CaCl_2 + CaSO_4 + MgO + Na_2O}{Al_2O_3 + SiO_2} = 0.90$$

Specific Energy = 168 Kwhr/mt of Feed

Material Balance Closure

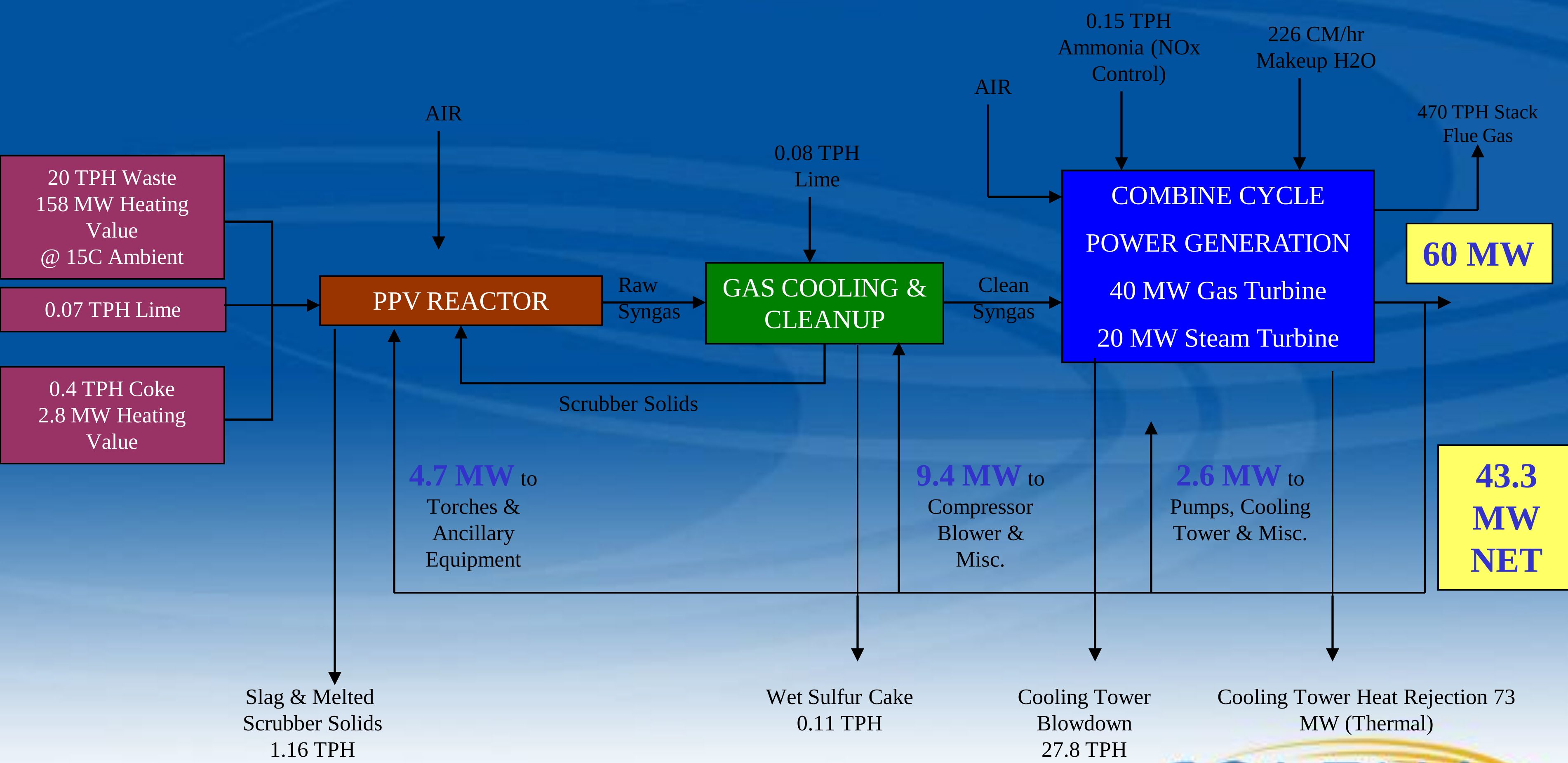
	Total	Oxygen	Carbon	
Input	19929	12811	7263	Kg/hr
Output	19929	12817	7263	Kg/hr
Delta	0	-5	0	Kg/hr

Average Tuyere Tip Temp. C 1396
Primary Tuyere Tip Temp. C 1396 **assuming** 3 **torches &** 3070 **Nm3/hr of total air through each tuyere.**
Design Primary Tuyere Tip Temp. C 1372

Technology and Process

Generic Project Overall Heat/Mass Balance

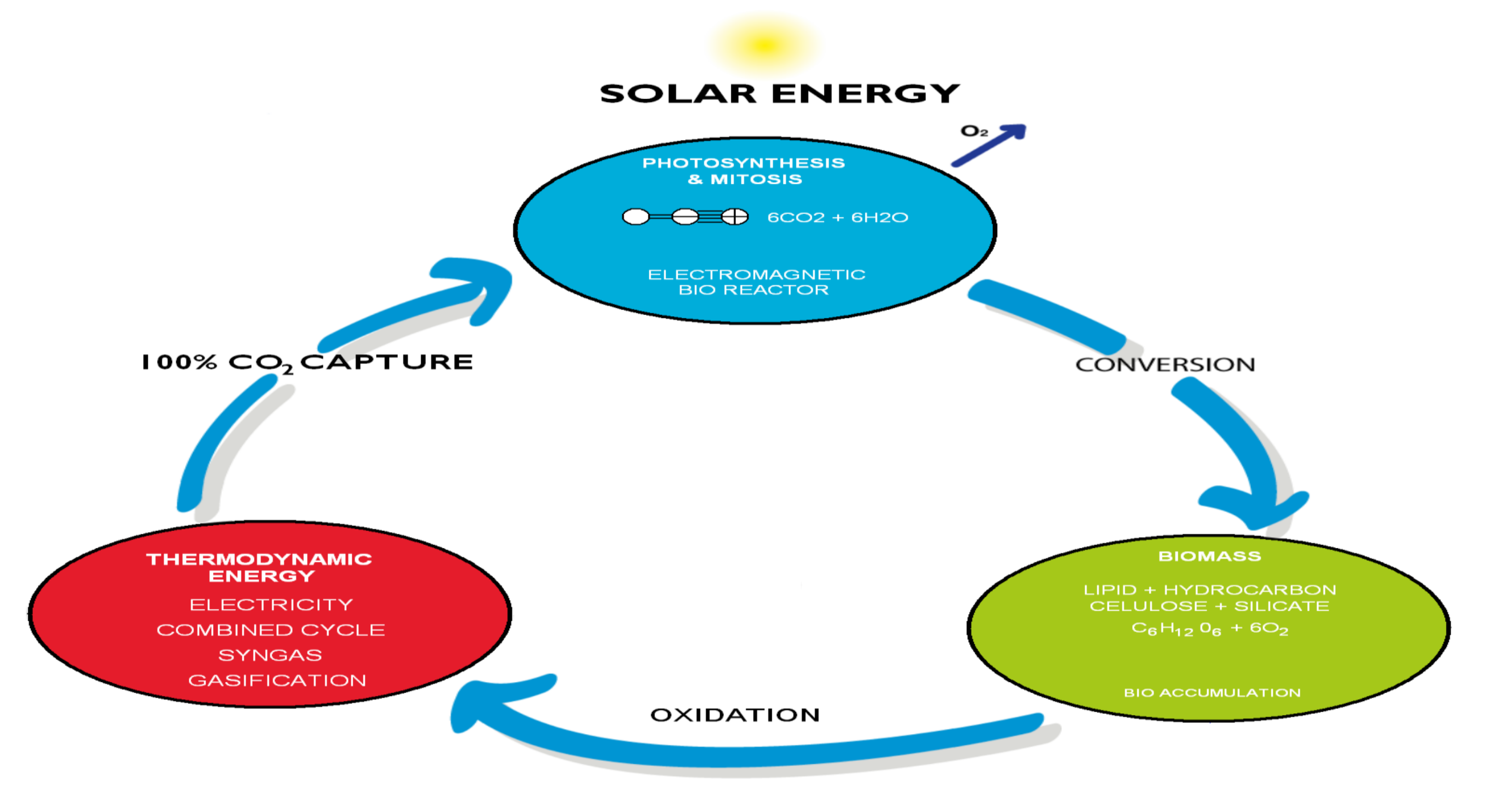
PGV Plant Producing 43 MW of Net Power from Mixed Industrial Waste



Solena BFS Division

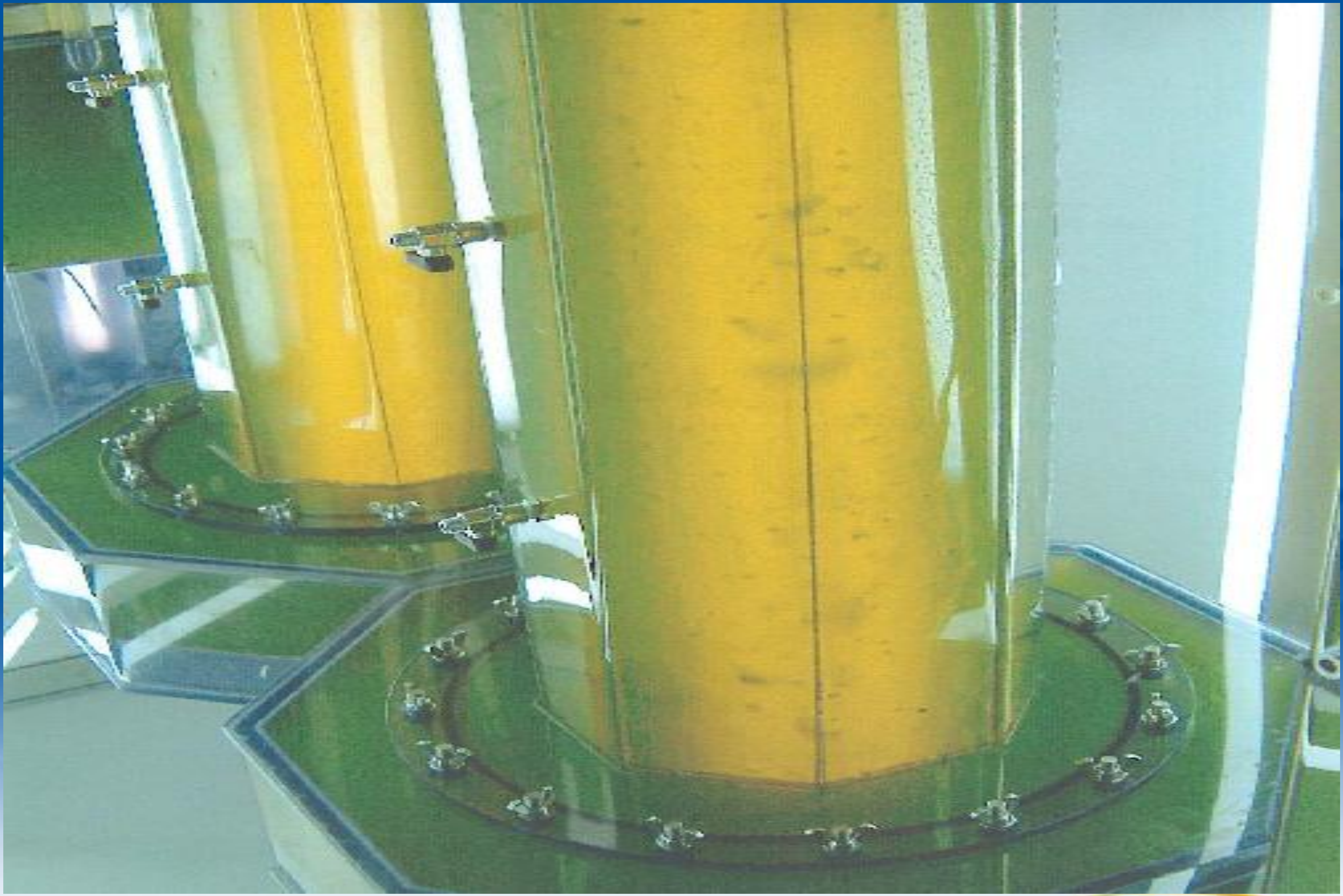
CO2 Sequestration - Phyto-Plankton Production

Zero Emissions CO2 Sequestration for Phyto-Plankton Production



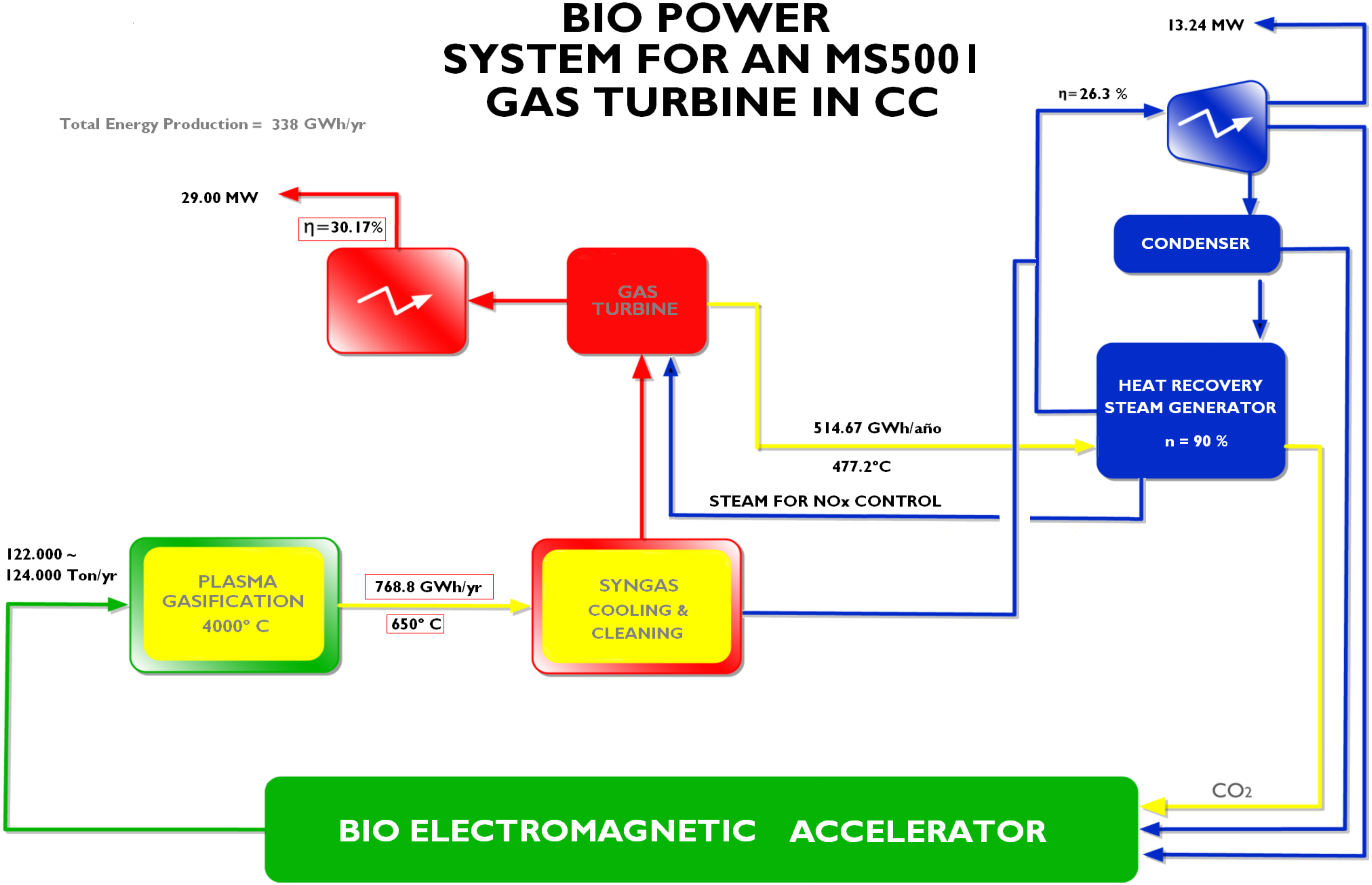
Solena CO2 Sequestration & Phytoplankton Production

- Partnership with Bio Fuel Systems, S.L. of Alicante
- Complete Sequestration of Exhaust gas from GT including CO_2 & NO_x
- Closed Loop Production by Photosynthesis of PhytoPlankton Species
- Biomass w/ 6000 Kcal/Kg – 40% Triglycerides Oils, 40% HydroCarbon



BIO POWER
SYSTEM FOR AN MS5001 GAS TURBINE IN CC

Total Energy Production = 338 GWh/yr



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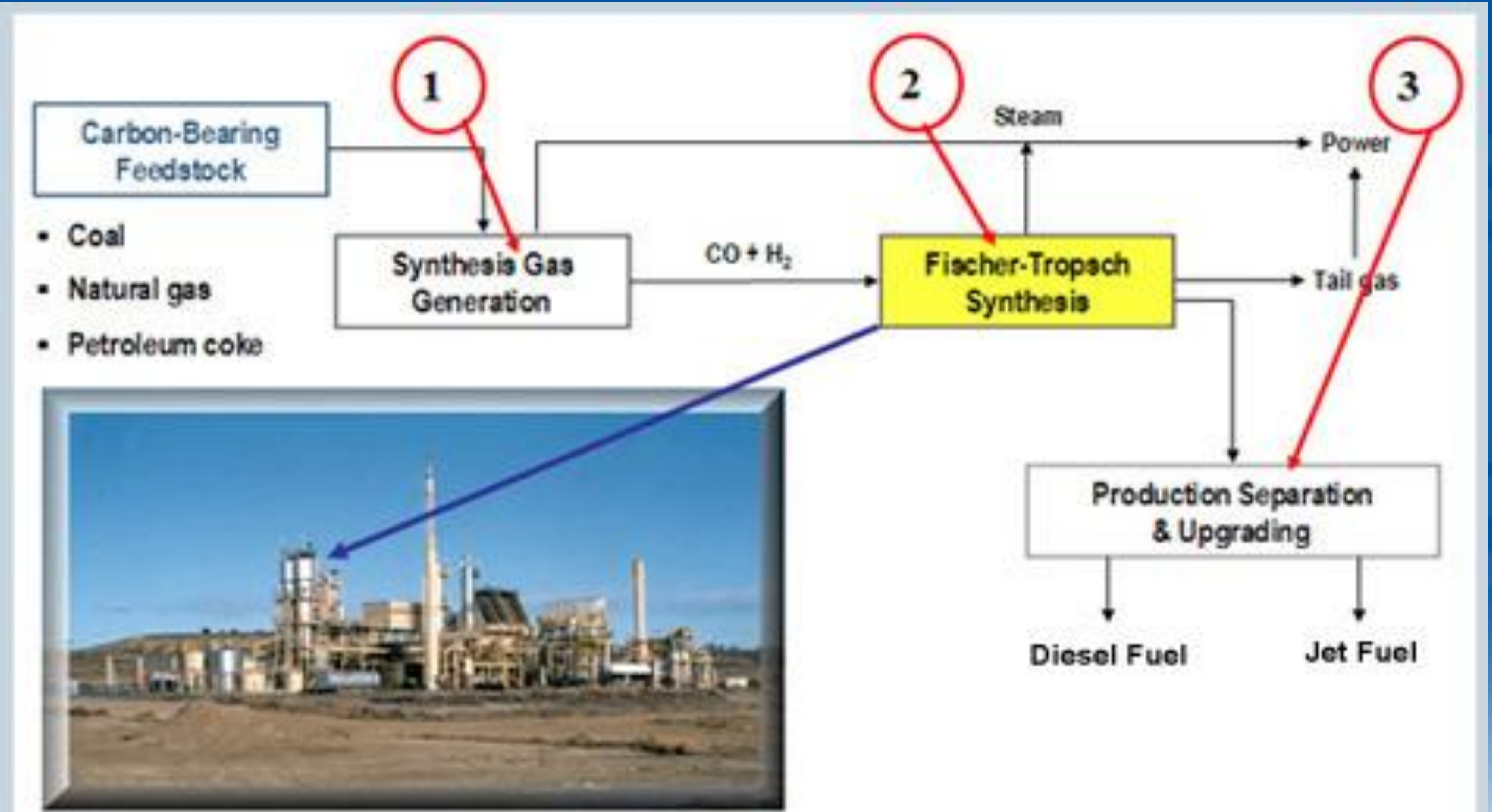
Solena BTL Division
Production of Aviation Bio-Fuel

Solena Biomass to Liquid Fischer Tropsch Program

- Syngas Conversion by Fischer Tropsch technology into Clean Diesel + Aviation Fuel
- Partnership with RenTech, Inc. of California
- RenTech F-T Program Suitable w/ Iron Catalyst and H2/CO Ratio Compatibility
- Supported by Current RenTech CTL program

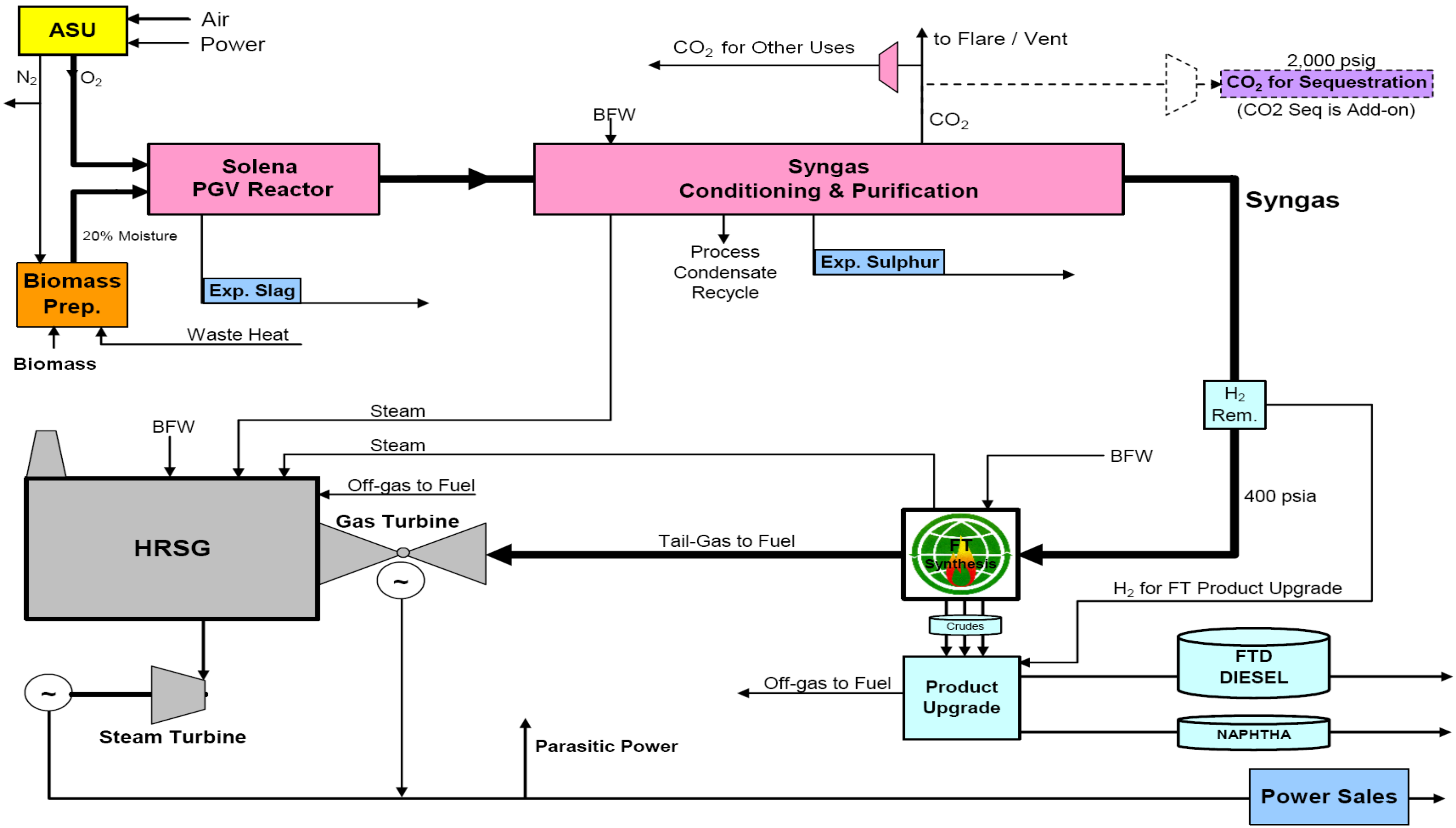
RENTECH FISCHER ROPSCH



Synhytech – Pueblo, Colorado, 1992

Once-Through FT System

Biomass Gasification Yielding Rentech FT Fuels & Power



Advantages of Solena's Bio Energy

- Flex Fuel enables Unlimited Sources of Biomass utilized as feedstocks
- Zero Emissions w/ CO2 Sequestration
- Clean & Cost Effective Bio-energy production:
  - Bio-Power (Distributed & Close Loop)
  - Bio-Fuel (Jet Fuel and Sustainable FTDiesel)
- More efficient and reliable than other forms of renewable energy

Good News from US EPA!

- EPA Proposes to Classify Gasification Plant as
  - Fuel Manufacturing Facility
  - Safer, More Efficient & Distinguished From Incinerators or Thermal Waste Disposal Plants
- Even Hazardous Waste are Considered Fuel Feedstock and Not Solid Waste – Excluded from RCRA Permitting
- Gasification Promotes the Production of “Marketable Fuels and Chemicals from Materials that Were Otherwise Destined for Waste Treatment, Disposal, or a Less Environmentally Benign Recycling Activity”.

PYROGENESIS

ENERGY FROM INNOVATION

INNOVATIVE PLASMA WASTE TO ENERGY SOLUTIONS

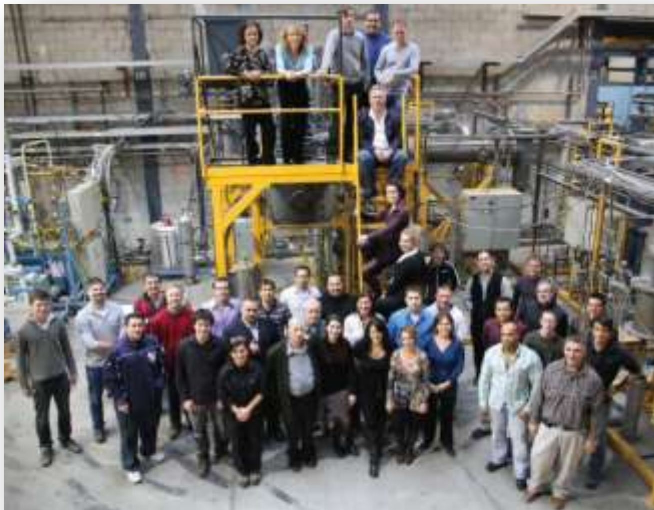
Power Sources Focus Group

Gillian Holcroft: Chief Operating Officer

September 28, 2011

COMPANY OVERVIEW

PyroGenesis *is a leader in the design, development, manufacture and commercialisation of advanced plasma waste destruction and waste-to-energy systems*



- 48 skilled employees (more than 70% are engineers, scientists and technologists)
- 7 technology patents in 28 jurisdictions
- 6 plasma waste destruction systems in operation and/or being commissioned
- 27 plasma torch systems sold to date
- ISO 9001 Registration

CERTIFICATE
OF REGISTRATION
PyroGenesis Canada Inc.
Quality Management System
ISO 9001:2000
SAI GLOBAL

6000 m^2 manufacturing facility in Montreal, Canada

PYROGENESIS
ENERGY FROM INNOVATION

PAWDS

Plasma Arc Waste Destruction System

- Applicable for Marine Vessels & Mobile Land-Based Units
- Capacity: 0.5-15 tonnes per day

PRRS

Plasma Resource Recovery System

•Designed as a Clean and Efficient Waste to Energy Solution
•Transportable & Fixed Land-based Units
•Capacity: 2-100 tonnes per day
(larger systems planned)

PAWDS

Market for Compact Systems:

- Patented technology for the safe and efficient destruction of shipboard waste
- Initially designed for marine industry requirements where space constraints and high waste disposal costs are serious issues
- 10+ year development collaboration with US Navy
- Unit can be used as a mobile land-base waste destruction system for solid, liquid and gaseous wastes , with energy recovery capability

PAWDS in Operation:

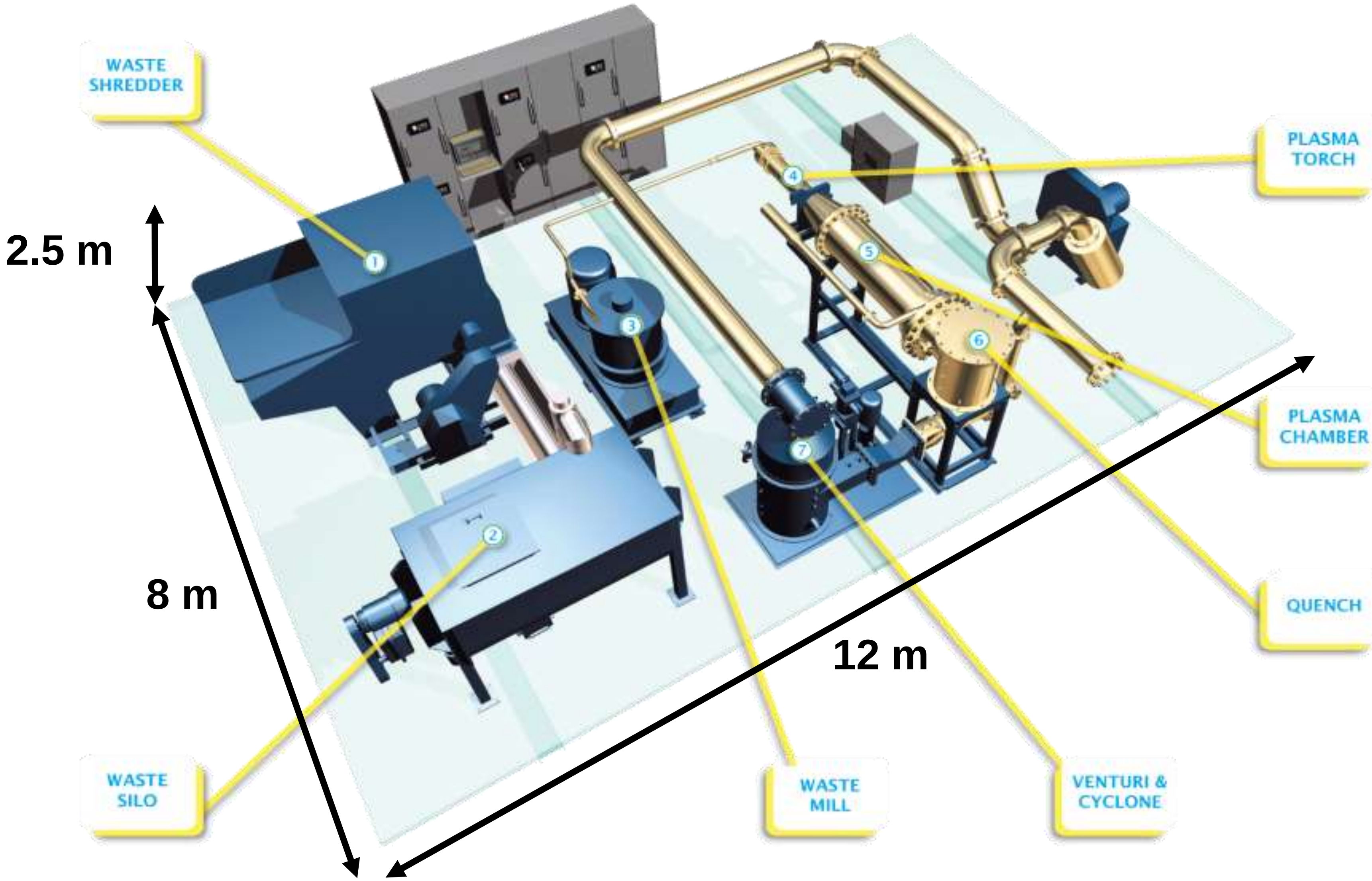
Carnival Cruise Lines

System installed in October 2003 – the first marine plasma waste destruction system in the world

Northrop Grumman (CVN 78 Aircraft Carrier)

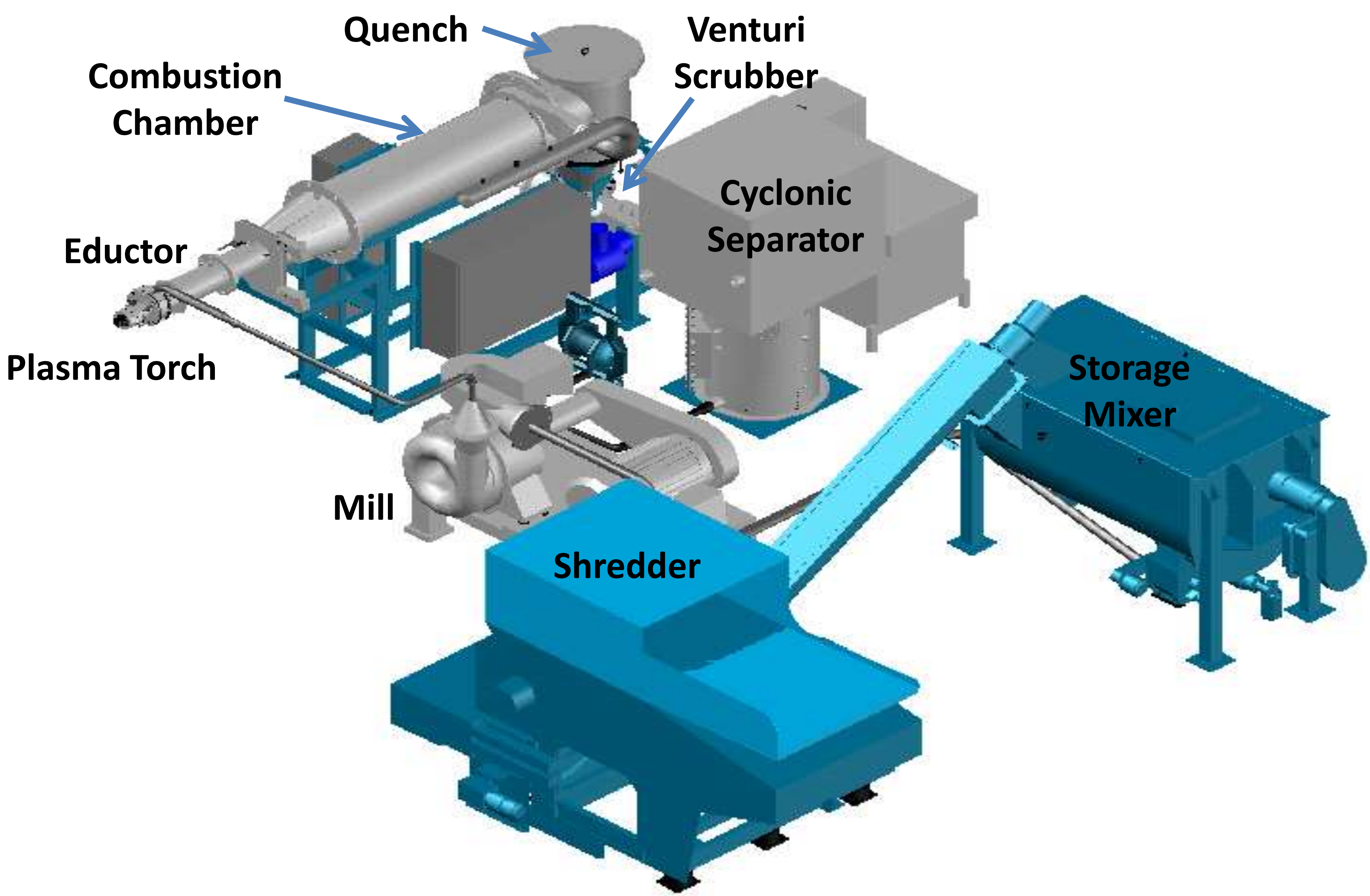
- Contract signed in 2008 to deliver 5 TPD PAWDS unit in Q3 2011 for the first ship of the CVN21 Air Craft Carrier series
- Passed U.S. Navy 60-day Endurance Test
- System passed Factory Acceptance Tests and is being prepared for shipment

PAWDS – COMPACT DESIGN



PYROGENESIS
ENERGY FROM INNOVATION

PAWDS – COMPACT DESIGN



PAWDS – COMPACT DESTRUCTION

- Safe with no risk of fires
- Meets or exceeds MARPOL regulations
- Rapid Start-up & Shutdown
- Less space and weight
- No visible plume or heat signature
- Fully Automatic / Sailor Friendly with minimum manpower
- Able to treat Cardboard, Plastics, Food, oily rags, Styrofoam, thin film plastics with minimal segregation

Typical PAWDS

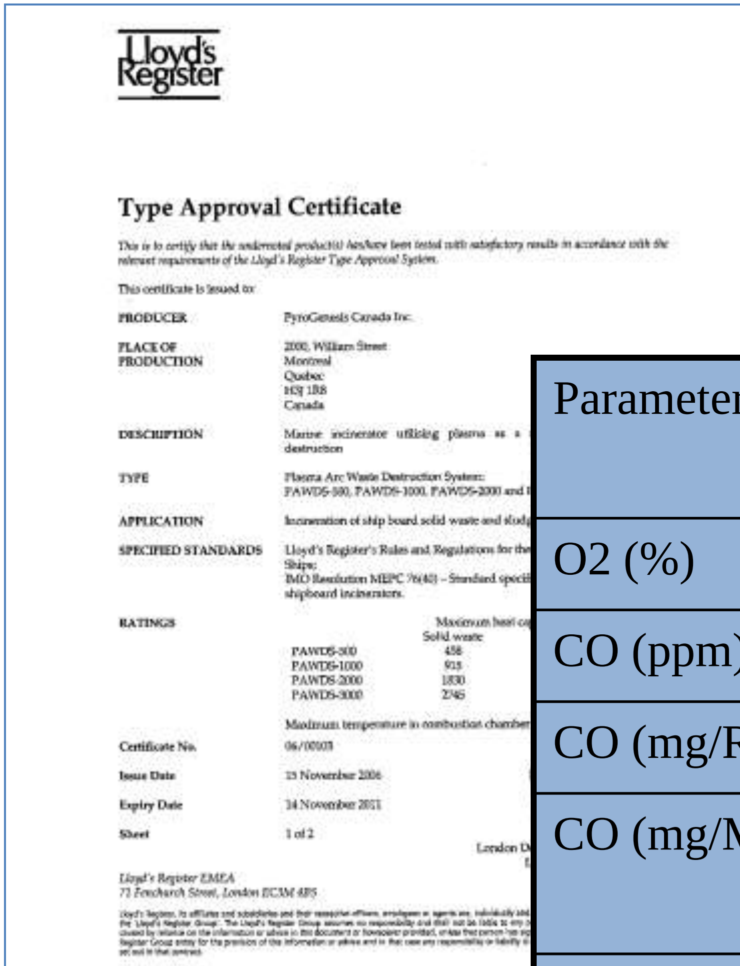
Capacity	440 lbs/hr
Power Requirements	425 kW
Footprint	675 ft^2
Weight	24 tons

Additional Features:

- **Energy Recovery** is an option
- Scalable design from 0.5 to 15 tons/day (1,000 to 33,000 lbs per day)
- Can treat Sludge Oil, other liquid wastes and gaseous waste (CFC, HFC's)

PYROGENESIS ENERGY FROM INNOVATION

PAWDS – MARPOL COMPLIANCE



Lloyd's Register

Type Approval Certificate

This is to certify that the undernoted product(s) has/have been tested with satisfactory results in accordance with the relevant requirements of the Lloyd's Register Type Approval System.

This certificate is issued to:

PRODUCER: PyroGenesis Canada Inc.

PLACE OF PRODUCTION: 2000, William Street, Montreal, Quebec, H3J 1R8, Canada

DESCRIPTION: Marine incinerator utilising plasma as a … destruction

TYPE: Plasma Arc Waste Destruction System: PAWDS-500, PAWDS-1000, PAWDS-2000 and …

APPLICATION: Incineration of ship board solid waste and sludg…

SPECIFIED STANDARDS: Lloyd's Register's Rules and Regulations for the … Ships; IMO Resolution MEPC 76(40) – Standard specifi… shipboard incinerators.

RATINGS:

	Maximum heat ca… Solid waste
PAWDS-500	458
PAWDS-1000	915
PAWDS-2000	1830
PAWDS-3000	2745

Maximum temperature in combustion chamber…

Certificate No.: 06/00103

Issue Date: 15 November 2006

Expiry Date: 14 November 2011

Sheet: 1 of 2

London D…

Lloyd's Register EMEA
71 Fenchurch Street, London EC3M 4BS

Parameter	Measured value	MARPOL guidelines
O2 (%)	11.2	6 to 12
CO (ppm)	5	-
CO (mg/Rm3)	6	-
CO (mg/MJ corrected at 11% O2)	3.1	200
Off-gas – Opacity (%)*	< 5	< 20
Ash – UNBURNED COMPONENTS (550 °C) (%)	NA**	< 10

PYROGENESIS
ENERGY FROM INNOVATION

PAWDS AVAILABLE

REQUIREMENT	PAWDS	MINI-PAWDS	ELECTRIC GARBAGE CAN
Max Daily Capacity (lbs)	6,800	720 to 3,060	300
Type of Waste	Navy mix incl. plastics, rags, food, sludge oil	Navy mix incl. plastics, rags, food, sludge oil	Navy mix incl. plastics, rags, food, sharps, biohazards
Capacity (lbs/hr)	400 to 450	180	50
Operating time (hrs/day)	15 to 17	4 - 17	6
Size – 1 deck (LxW)	33 x 20.5	18.5x14.5	6.6 x 8.3
Footprint (ft^2)	675	213	55
System Weight (‘000 lbs)	50	18	15
Comparative Cost (order of magnitude)	100%	60%	15-25%

PAWDS MARKETS

Marine

- US Navy Air Craft Carriers
- US Navy Destroyers
- Cruise Lines
- Cargo Ships
- Ferries

Liquid & Gaseous Wastes

- Ozone Depleting Substances (CFC's)
- Sludge Oils
- Liquid Wastes (paints, solvents…)

Mobile Units

- US Military
- FEMA (Disaster relief)

PRRS - Plasma Resource Recovery System

Medical Waste

MSW

Hazardous Chemicals

1. Primary Gasification Furnace using graphite electrodes
2. Secondary Gasification Chamber, with air plasma torch and patented eductor
3. Quench to prevent dioxin and furan formation
4. Air Pollution Control tailored to waste stream

Video of process available at www.pyrogenesis.com

Gasification

Thermal conversion of organic matter into synthesis gas consisting primarily of CO and H_2 with only a small amount of oxygen

Syngas
(CO & H_2)

Chemical Products

Vitrification

Inorganic material is melted at 1600°C to produce an inert slag that is safe for use as a construction material

PYROGENESIS
ENERGY FROM INNOVATION

Besides MSW, PRRS can process the following…

PCB's-
Transformer oils

Fly Ash

Medical waste

Construction waste

Hazardous
Chemical waste

Waste & sludge oils

PRRS – IMPROVED PLASMA PROCESS

PyroGenesis' PRRS avoid the problems that have plagued traditional plasma-based processes: reliability, robustness and cost constraints

1 Patented two-stage process ensures:

- a reliable and robust operation
- Improved and efficient conversion of waste to syngas
- Higher quality, more consistent syngas produced

2 Patented graphite arc plasma furnace offers:

- Superior energy efficiency compared to conventional plasma torch fired furnaces
- Lower system capex and opex

Improved plasma process results in a commercially viable waste to energy solution

PRRS ELECTRICITY PRODUCTION ESTIMATES

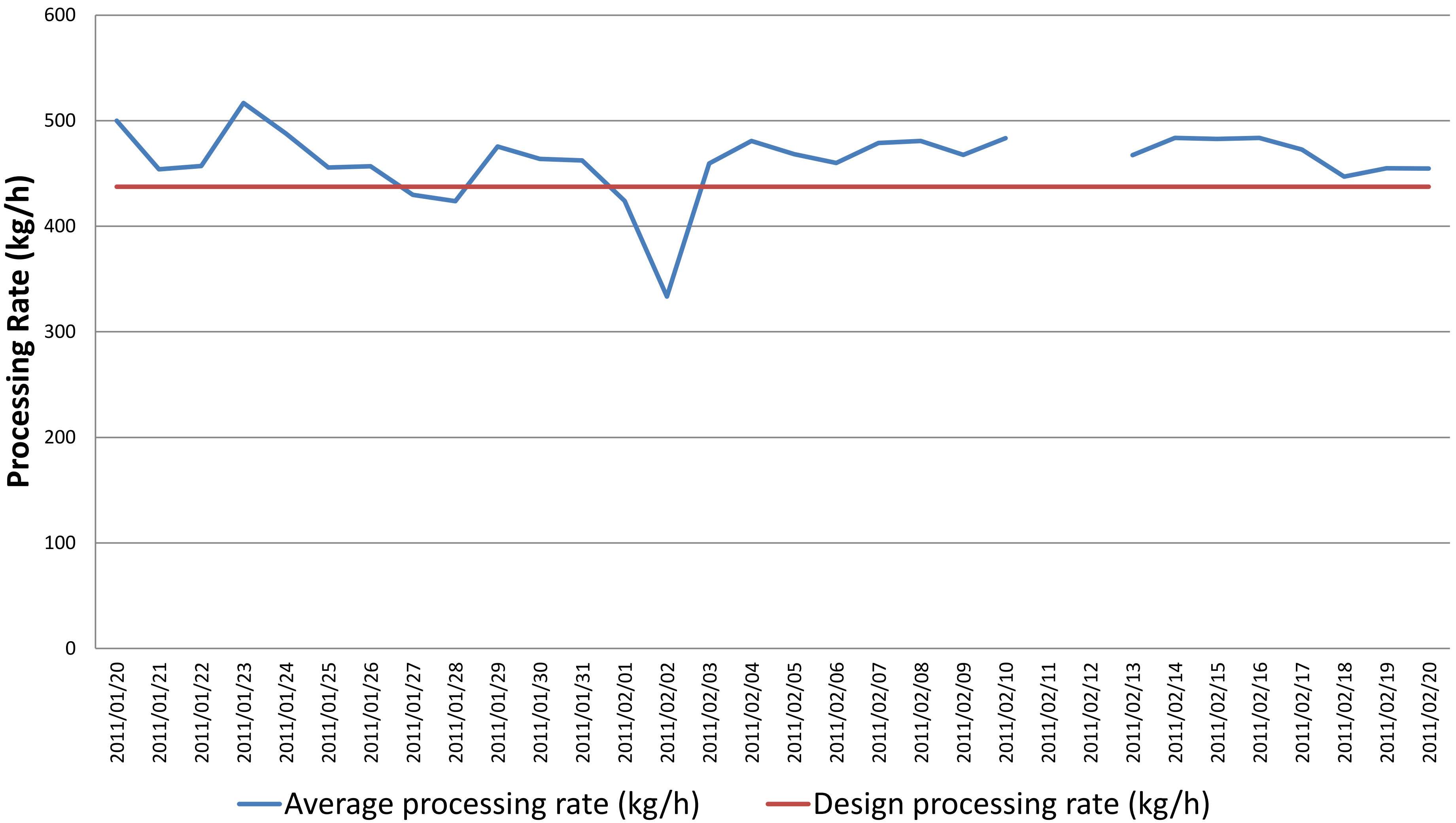
PLANT CAPACITY	NET ELECTRICITY OUTPUT
10 TPD	0 (neutral)
50 TPD	900 kW
100 TPD	2,300 kW

1) Assumes syngas being fed to internal combustion engine used to produce electricity

2) Output estimates based on selected municipal solid waste composition

Video of Hurlburt Field Operation

Waste Feed Rate vs. Design Capacity

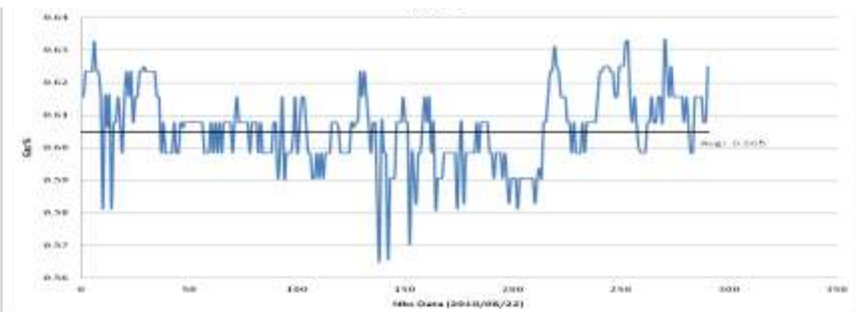


PYROGENESIS
ENERGY FROM INNOVATION

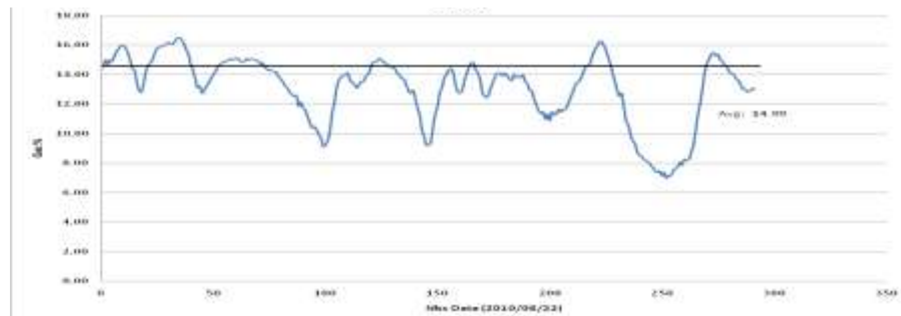
Syngas Composition

System is able to produce a consistent flow and quality of syngas to power the GE Jenbacher gas engine and produce electricity. Only fuel is the garbage.
No other gases are introduced!

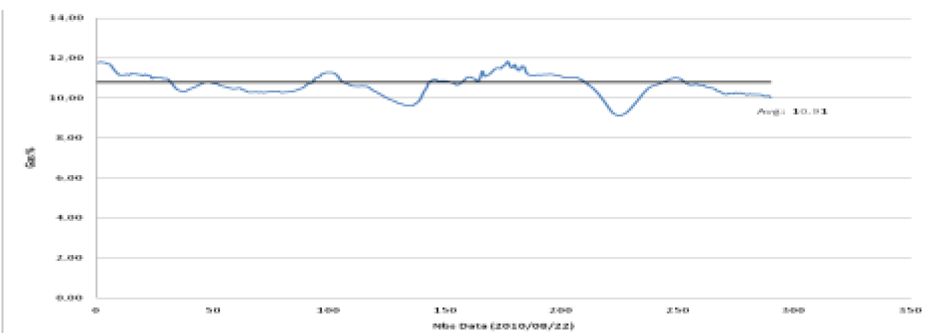
Component (% vol/vol)	Simulated value	Average Value
CO	22	16
CO2	7	10
H2	19	20
N2	52	54



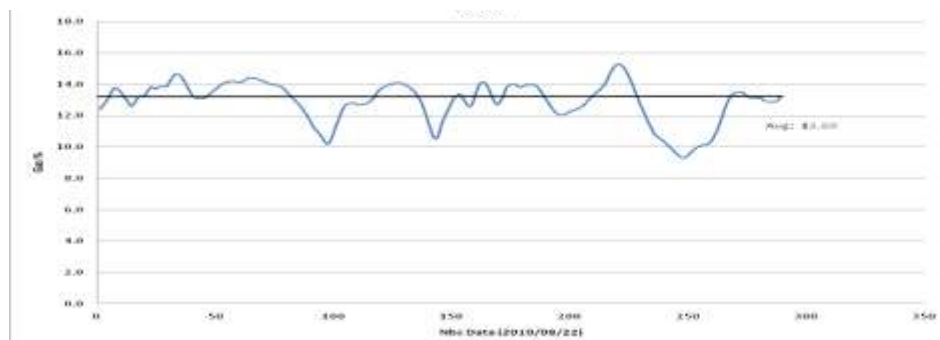
Residual Oxygen



Hydrogen



Carbon Dioxide



Carbon Monoxide

PYROGENESIS ENERGY FROM INNOVATION

TCLP results from Hurlburt Slag

Contaminant	EPA Hazardous Waste #	Regulatory level (mg/L)	Slag concentration (mg/L)
Arsenic	D004	5.0	0.002
Barium	D005	100.0	1.253
Cadmium	D006	1.0	0.001
Chromium	D007	5.0	0.252
Lead	D008	5.0	0.004
Mercury	D009	0.2	0.0002
Selenium	D010	1.0	0.003
Silver	D011	5.0	0.010

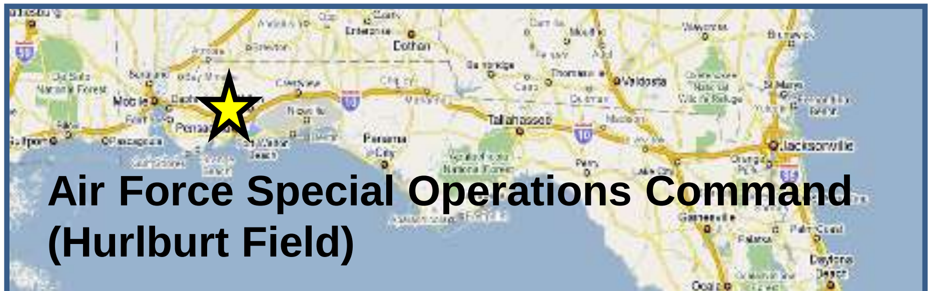
PRRS MARKETS

Up to 10 TPD	• Hospital / Clinical Waste • Hazardous Waste • Pharmaceutical Waste • Apartments, Hotels… • Island Communities • Military- Transportable Units
20 to 75 TPD	• Hazardous Waste • Industrial Waste: Chemical, Mining, & Metallurgical… • Island Communities • Airports
100 to 250+	• Industrial Waste • Municipal Solid Waste

PYROGENESIS
ENERGY FROM INNOVATION

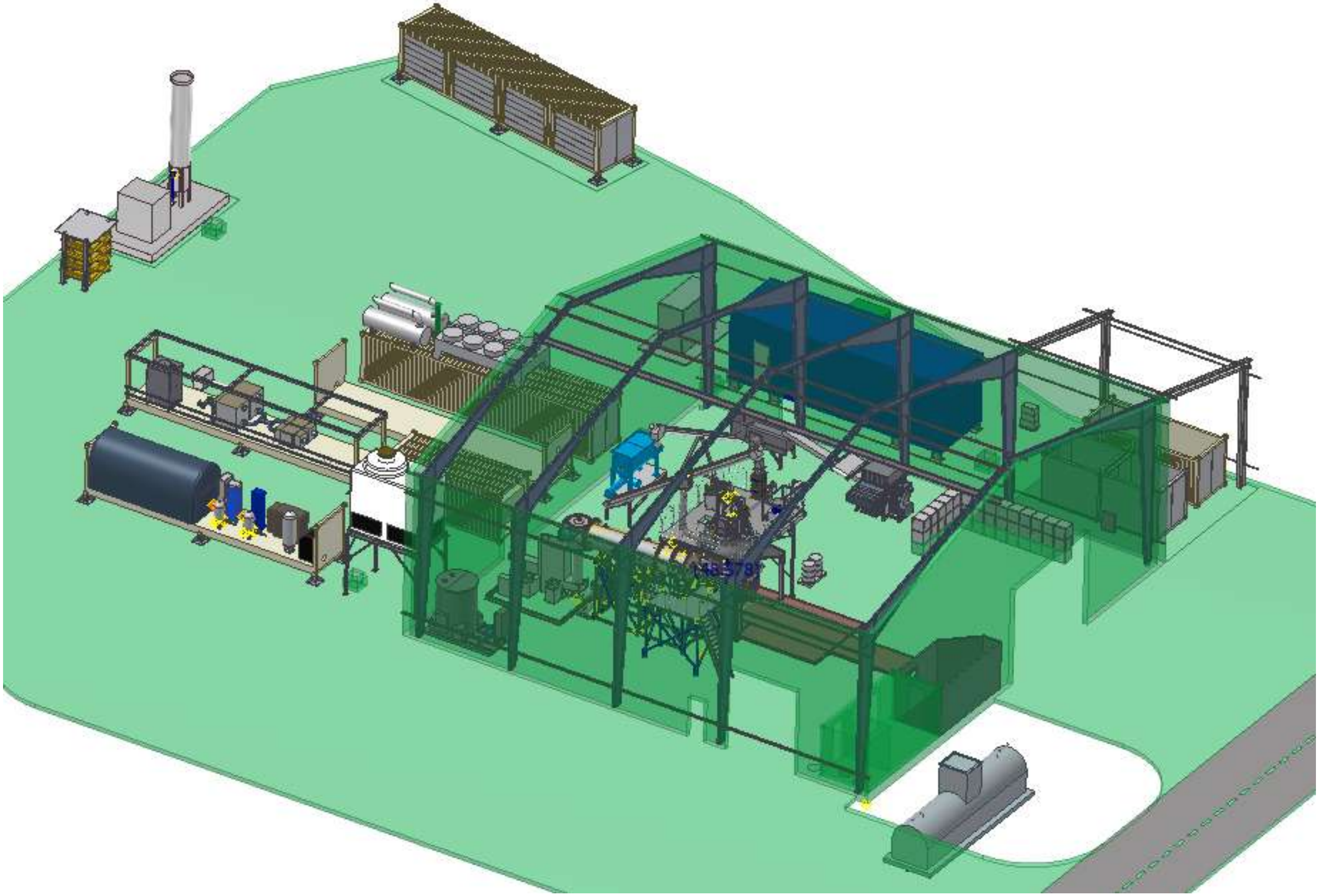
PRRS DELIVERED TO THE US AIR FORCE

- The 10.5 TPD Transportable Plasma Waste to Energy System located at a US Air Force base in Florida is designed to process MSW, Hazardous Waste, and Medical Waste . The system was accepted by AFSOC in June 2011.
- Turn-key project on Greenfield site
  - PyroGenesis responsible for facility, permits and plasma system
  - 80 by 80 foot facility housing skid-mounted sub-systems
  - Gas Cleaning and Engine Skids located outside of facility on concrete pads
- The PRRS is producing a steady, clean flow of syngas and generates electricity through an internal combustion engine. No other gas is used to operate the IC Engine.
- Proposal has been submitted to demonstrate the generation of liquid fuels from Syngas



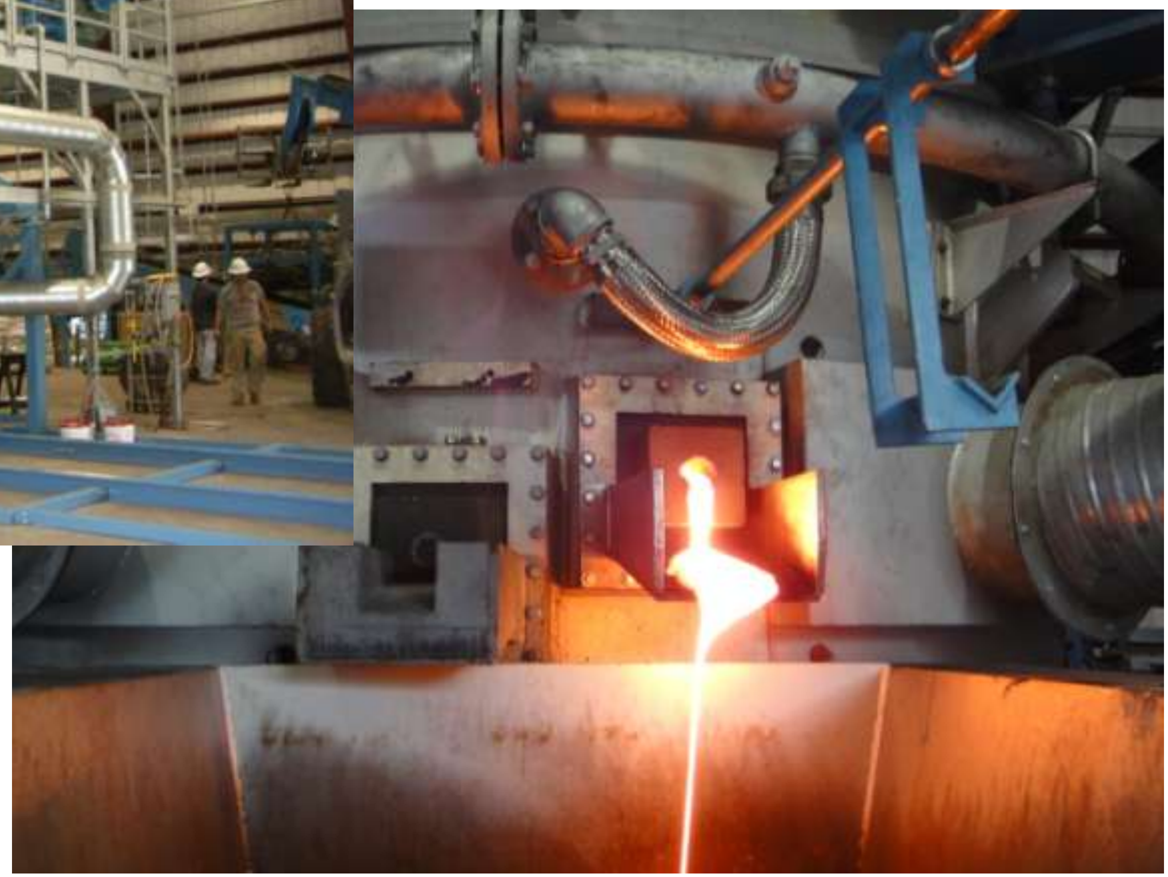
PYROGENESIS
ENERGY FROM INNOVATION

PRRS/USAF – HURLBURT FIELD SITE



PYROGENESIS
ENERGY FROM INNOVATION

PRRS/US AFSOC : Graphite Arc Plasma Furnace



PYROGENESIS ENERGY FROM INNOVATION

PRRS/USAFSOC : Ribbon-cutting Ceremony

April 26th 2011

PYROGENESIS
ENERGY FROM INNOVATION

PRRS TECHNOLOGY INTEGRATION

- Recycling / Composting
- Anaerobic Digestion
- **PRRS**
- Other…

Co-Fire

Syngas

- Syngas Fired Engine
- Gas Turbine
- Syngas Fired Boiler
- WHB
- Co-Generation

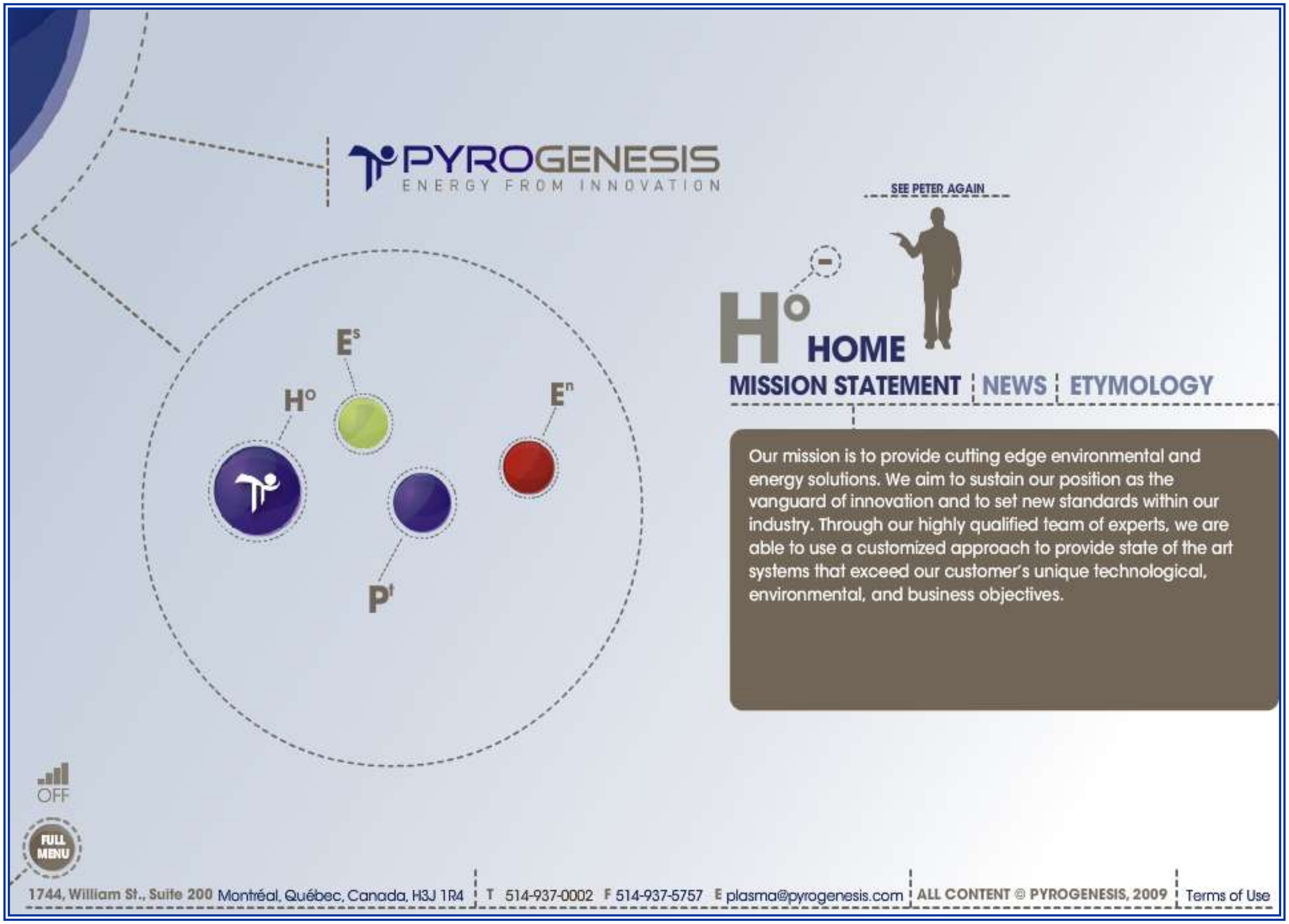
Syngas

- Liquid fuels
- Fuel cells

"Plasma gasification complements current waste management strategies by processing and adding value to waste not treatable by other means."

PYROGENESIS

ENERGY FROM INNOVATION



www.pyrogenesis.com

Introduction to adaptiveARC

Power Source Focus Group Meeting on Plasma Gasification

September 28, 2011

adaptiveARC

Energy That Cleans®

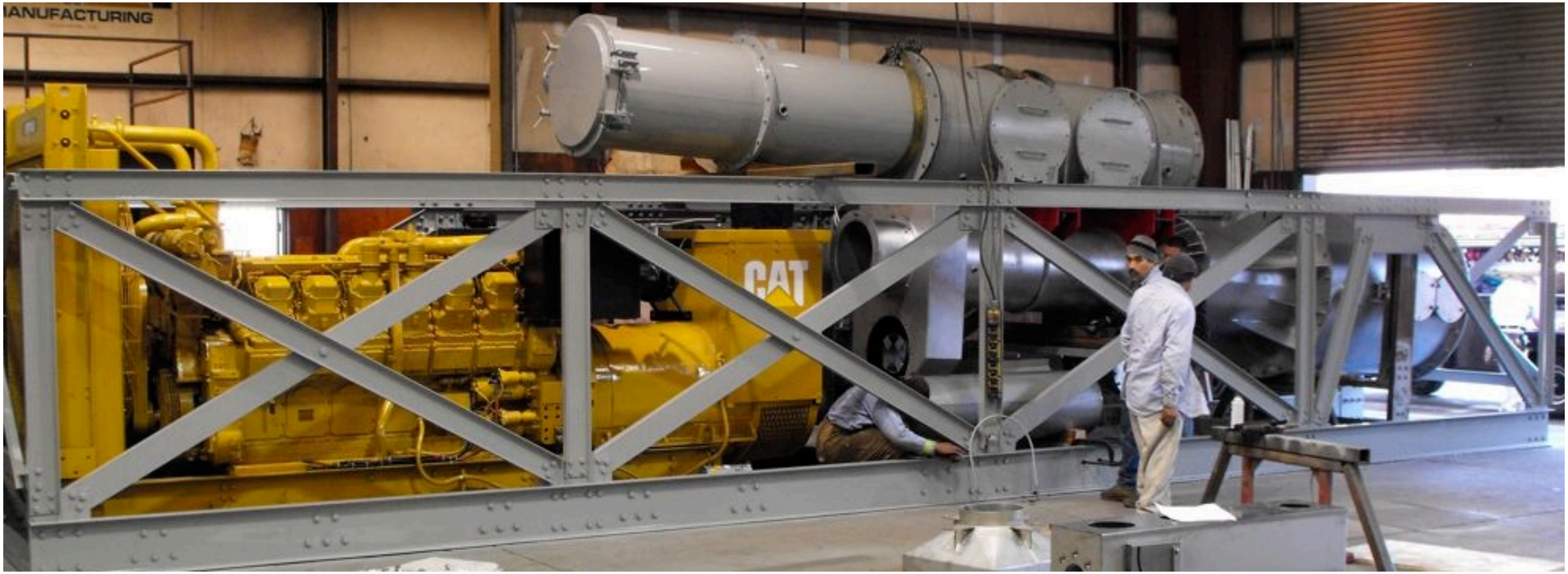
adaptiveARC Breakthrough Innovation : Energy that Cleans®

We transform low-value, hazardous materials into high-value products for industries and communities around the world:

- Creating renewable energy
- Reducing the toxic impact of waste
- Providing air, land and water remediation

Key differentiators:

- Price and Size: 40 - 70% more economical
- Flexibility : Portable, Modular and Scalable
- Best Available Control Technology (BACT)
- Clean and Profitable Energy Generation



Energy That Cleans® – adaptiveARC™ ce25 available today

Process 25 tpd and generate 500 kW clean renewable energy

adaptiveARC

Energy That Cleans®

adaptiveARC™ Innovations Advantage

8th generation technology changes the game

Key innovations drive COST and FLEXIBILITY advantages of the adaptiveARC system:

- Design principles:
  MOBILE, MODULAR and SCALABLE
- Proprietary and Patented Torch Design
- Pulsed Plasma Technology
- Regenerative Cleaning™
- Best Available Control Technology (BACT)
- Clean and Profitable Energy Generation
- Design criteria & specifications =
  MASS PRODUCTION

The combination of these advancements is COOL PLASMA® Gasification

Cool plasma gasification	Clean / profitable
Plasma arc gasification	Clean / expensive
Pyrolysis / Gasification	Clean / limited
Mass burn incineration	Dirty / proven

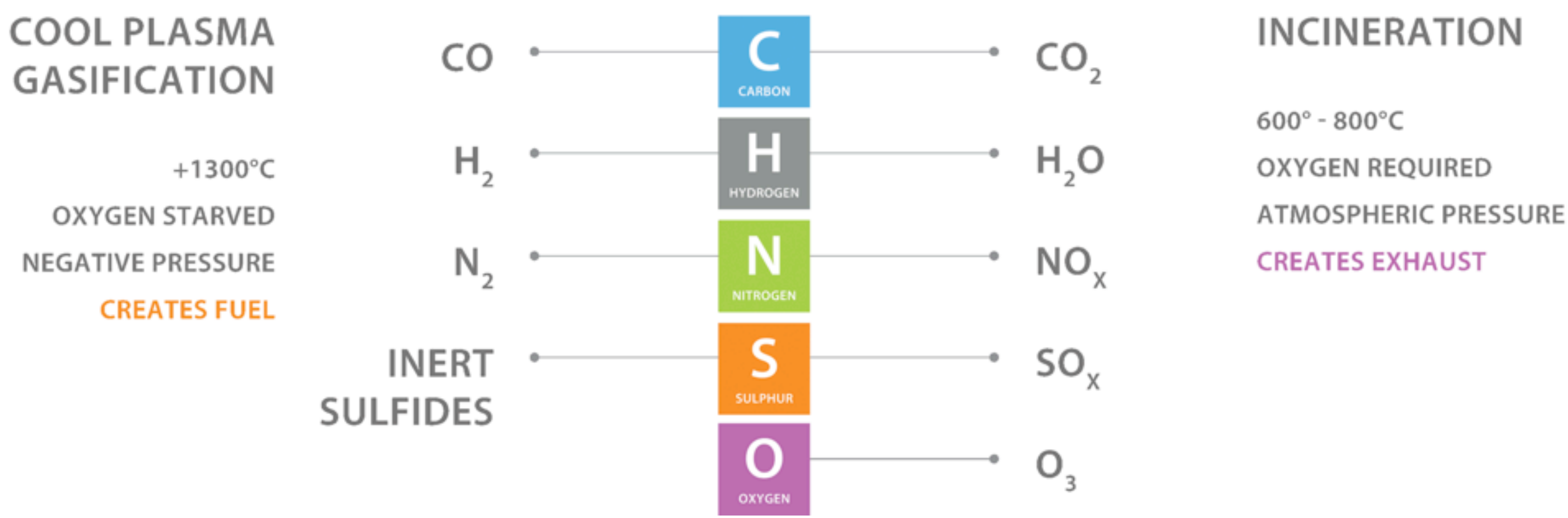
Gasification Today

Proven

- Gasification is older than the light bulb
- More energy-efficient than combustion
- More than 140 plants in 26 countries generating more than 75,000 MW
- Expected to grow by 70% by 2015

Clean and Renewable

- Gasification is the opposite of incineration
- Plasma arc is the cleanest form and recognized as state-of-the-art
- Biomass is the leading source of renewable energy according to The Department of Energy



An Essential Solution: COOL PLASMA® gasification creates fuel and reverses environmental damage.

Chemical compounds lose their bonds in high-temperature oxygen-starved environments

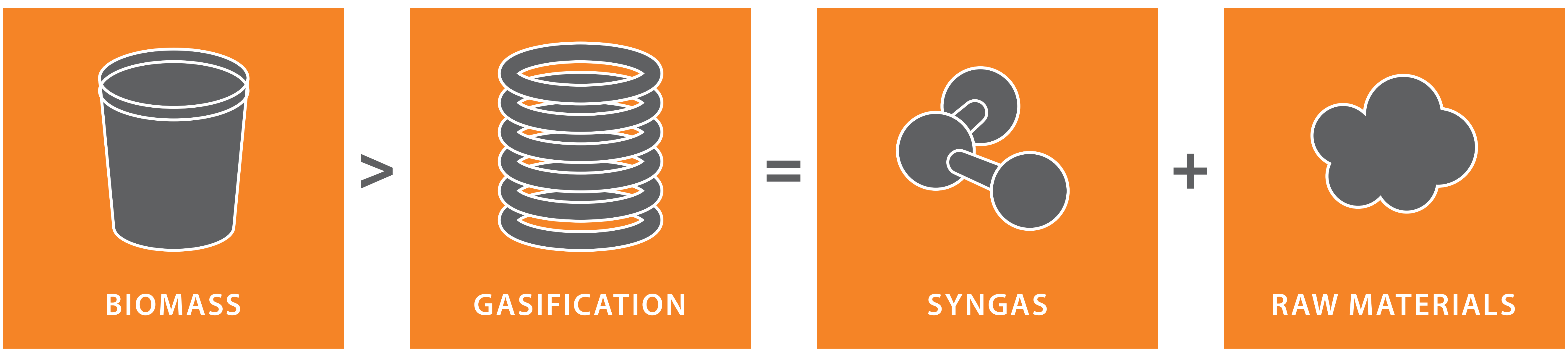
- Volume reduction about 95%
- The primary output is valuable syngas that can be converted to clean energy
- The residual solids are commercial

Incineration and gasification are opposite:

- incineration creates exhaust
- gasification creates fuel

Unlike solar and wind COOL PLASMA® gasification reverse environmental damage.

- Methane, VOCs and HAPs are converted to syngas or inert compound

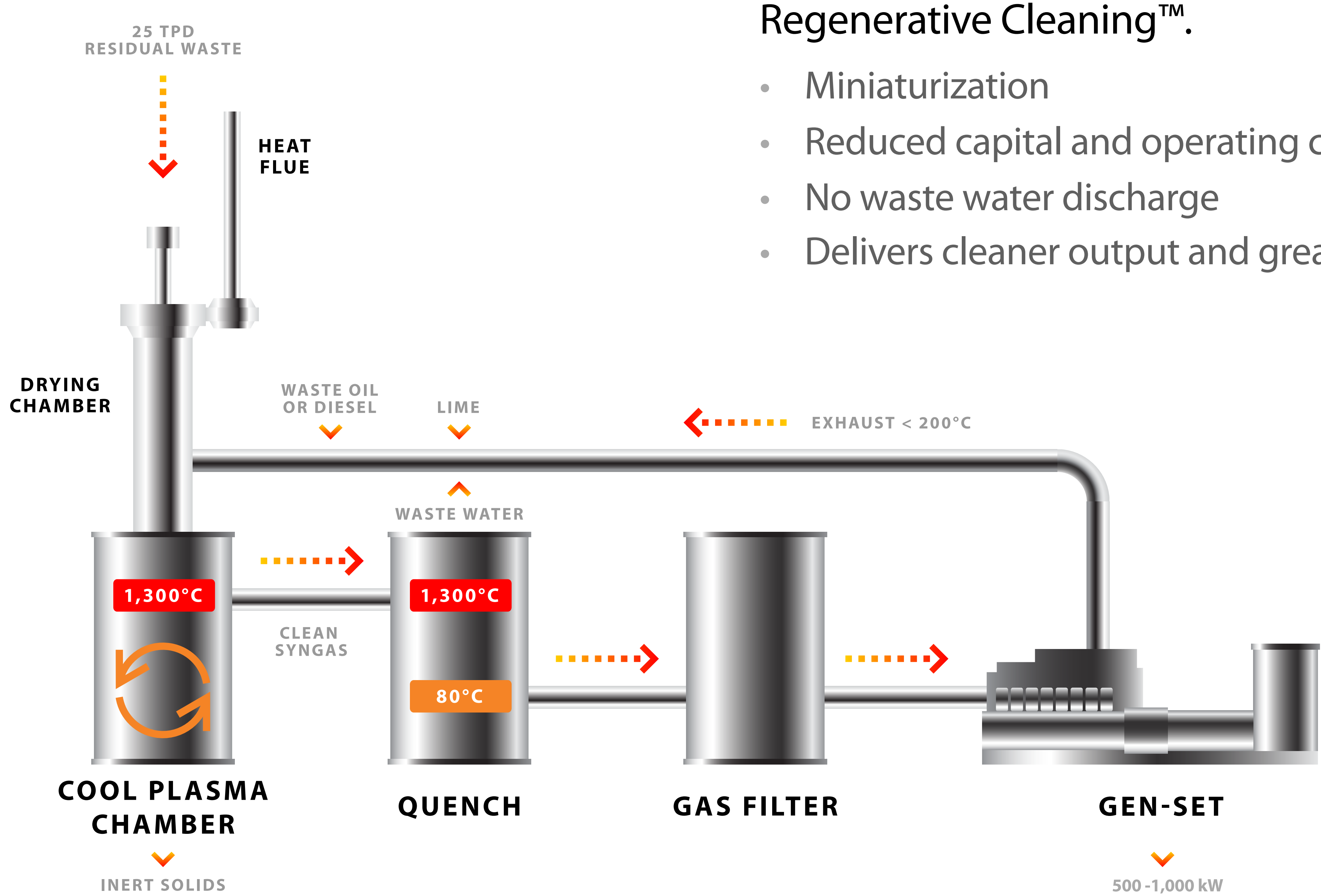


COOL PLASMA® Gasification

The combination of our unique torch and gasifier

Deep integration of several gasification functions into a single elegant design we call Regenerative Cleaning™.

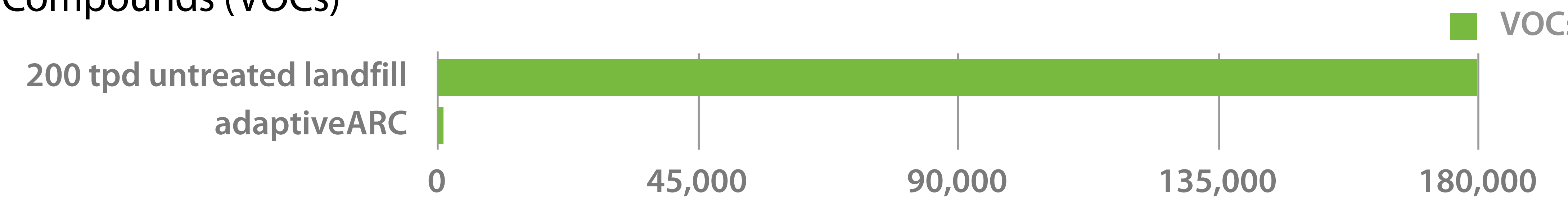
- Miniaturization
- Reduced capital and operating costs
- No waste water discharge
- Delivers cleaner output and greater control



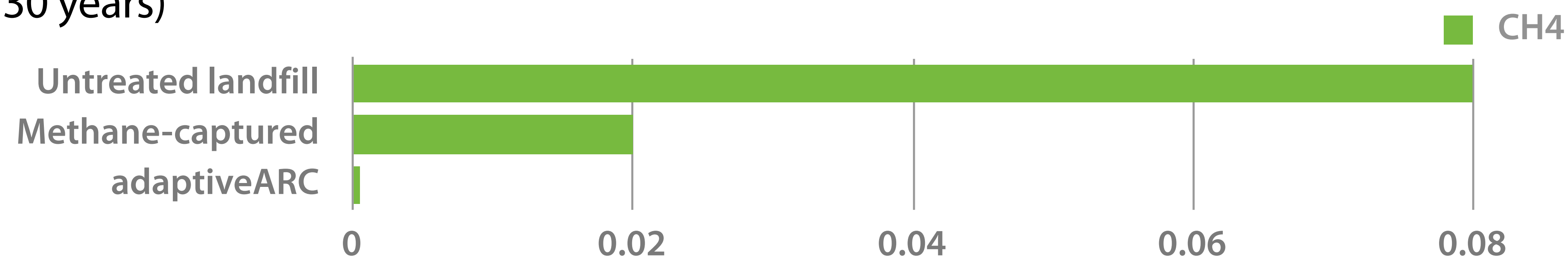
Remediation and Emissions Reduction: adaptiveARC utilizes 12 individual control technologies to mitigate environmental impact

Complete elimination of water waste

Volatile Organic Compounds (VOCs)



Methane (per ton over 30 years)



Combustion Emissions

Emission	CA requirements	adaptiveARC	
NOx	1.100	0.431	g/bhp-hr
CO	3.000	0.023	g/bhp-hr
VOC / HC	0.600	0.009	g/bhp-hr
PM	-	0.002	g/bhp-hr
SO2	-	0.05	g/bhp-hr

Results from Monterrey, MX pilot plant 6tpd

The adaptiveARC Advantage
System flexibility to solve waste needs

Unique Mobility and Size

- Transported in a standard 40′ x 8′ x 10′ shipping container.
- Simplicity of design allows for rapid deployment & installation.

Modular and Scalable

- ce25 system converts up to 25 tons per day into continuous 500kW of clean renewable energy.
- ce25 scales from 25 – 100 tons per day

100% Recyclable

- Any waste disposal: landfill, toxic waste elimination, bio-waste, tires, refinery waste, sewer sludge, medical waste, clean coal power, ethanol, liquid fuels, construction, military, mining.
- Our system also accepts waste fuels up to 50% moisture content.

adaptiveARC Compelling Economics

Clean plasma arc gasification benefits at a fraction of the cost

- Capital and operations costs 30-50% less than comparable systems
- Reduced manpower and consumables costs
  - Staff education requirement minimal
  - Innovative design requires little maintenance and replacement of parts

Easy to permit

- Less than 10,000 tpy exempt from EIA (each ce25 processes approx. 9000 tpy)

Contract Vehicles

- GSA, IDIQ, BOO, long term PPA
- Enhanced Usage, Turn-key Sale
- Equipment Leasing

Example Economics

REVENUES, USD | US Army Pilot Facility	1	2	3
Tip Fee			
Low	301,875	307,913	314,071
Expected	345,000	351,900	358,938
High	431,250	439,875	448,673
Energy Sales			
Low	786,600	802,332	818,379
Expected	828,000	844,560	861,451
High	993,600	1,013,472	1,033,741
Other Revenues			
Solid Byproducts	8,625	8,798	8,973
Carbon Credits	51,750	52,785	53,841
Renewable Energy Credits	82,800	84,456	86,145
Other Receipts	-	-	-
Total Revenues			
Low	1,231,650	1,256,283	1,281,409
Expected	**1,316,175**	**1,342,499**	**1,369,348**
High	1,568,025	1,599,386	1,631,373
EXPENSES, USD	**1**	**2**	**3**
Operating Expenses			
Labor	360,000	363,600	367,236
Consumables	321,713	324,930	328,179
Upgrade Fee	70,000	70,700	71,407
Insurance	13,162	13,293	13,426
Interconnect Fees	828	836	845
Permitting Fees	6,581	6,647	6,713
Other Expenses	-	-	-
Total Operating Expenses	**772,283**	**780,006**	**787,806**
Capital Expenses			
Finance Payments Due	482,966	482,966	482,966
Finance Cash Flow	(3,017,034)	482,966	482,966
Total Expenses	**1,255,249**	**1,262,972**	**1,270,772**
PROJECT INCOME, USD	**1**	**2**	**3**
Low	(23,599)	(6,689)	10,637
Expected	**60,926**	**79,527**	**98,577**
High	312,776	336,414	360,601
Cumulative			
Low	(23,599)	(30,288)	(19,651)
Expected	60,926	140,453	239,029
High	312,776	649,190	1,009,791

PROJECT SUMMARY		
Name	US Army Pilot Facility	
Start Date	January 1, 2012	
Cost of adaptiveARC equipment, USD	3,500,000	
Cost of additional equipment, USD	0	
Amount Financed, USD	3,500,000	
Breakeven		
Low	0	years
Expected	**0**	**years**
High	0	years
20-year cumulative income, USD		
Low	9,275,551	
Expected	**11,329,286**	
High	17,448,579	
External Benefits		
Jobs created	7	
Households powered	1,600	
Greenhouse gas reduction	12,938	tons / year

Financial Performance		
Investment IRR	**20 YEARS**	**10 YEARS**
Low	19%	12%
Expected	**22%**	**16%**
High	34%	30%
Net Present Value at 8%	**20 YEARS**	**10 YEARS**
Low	3,051,559	512,221
Expected	**4,011,190**	**1,125,548**
High	6,870,496	2,953,012

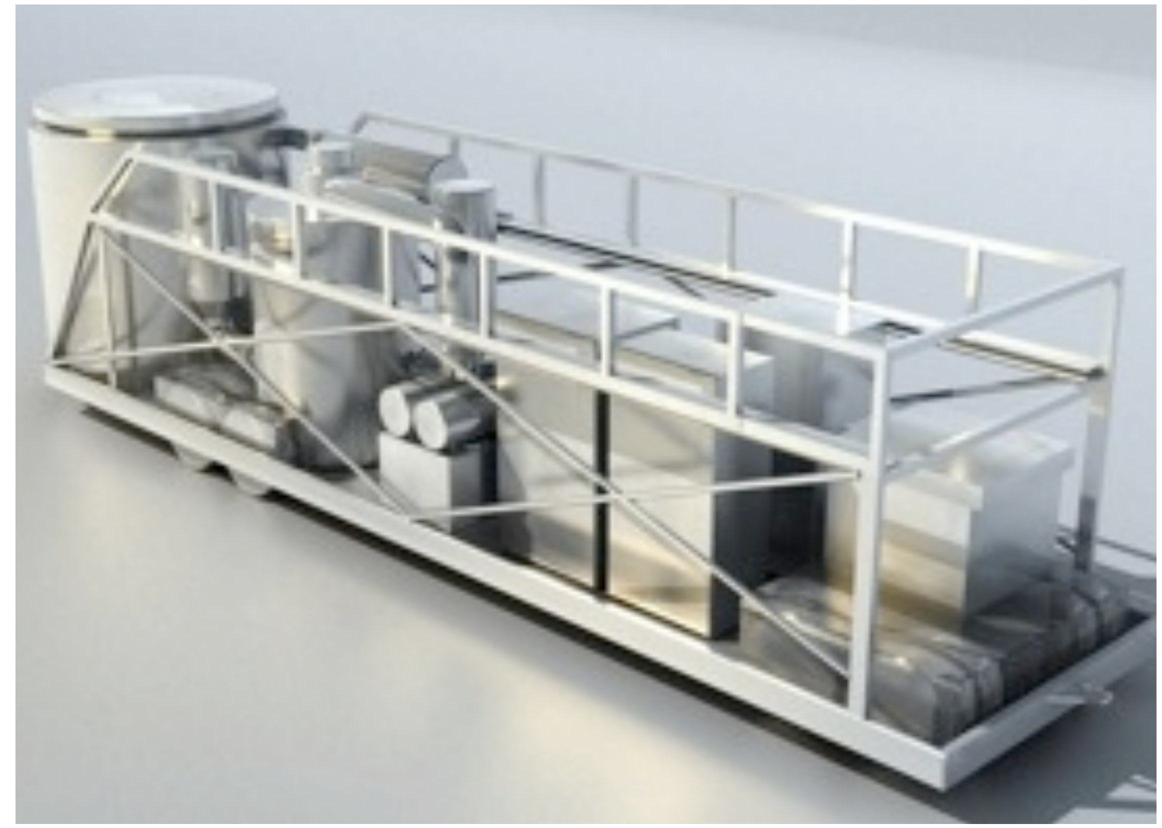
Example based on $40 per ton tip fee and $100 per MW PPA

adaptiveARC™ ce25 - Available Now
Proven success at commercial scale

Operating Since July 2010 in Mexico City

- Provides power to entire facility approximately 420kW continuous
- 8 to14 hours per day of operation 21-23 days per month
- Over 670 kg/hr dry material throughput
- Over 115 MW/hr per month
- Over 130 design improvements have been made based on results from testing, operating and demonstrating prototype
- Waste types processed:
    - Biomass, manure, hazardous waste, industrial waste, MSW residuals, plastic packaging, cardboard, paper pulp, sludge, carpet backing and construction debris

Product Development Pipeline



ce25 class

25 TPD
500 to 1,000 kW
in production

ce250 class

250 TPD
6 to 10 MW
1st deployment Jan 2014

Synthetic Liquid Fuels
Road map to the future

adaptiveARC has relationships with SGE (ScandGreen Energy) the largest biofuels producer in Scandinavia. They have specific FT processes designed to operate with the adaptiveARC ce25 to catalyze synthetic diesel and Kerosene (for JP-8, JP-A, JP-B, etc.)

Each ton of low-energy waste produces up to 40 gallons

- The fuel is in final form: ready for sale
- No bio-diesel or intermediate biofuels

Zero local emissions

Liquid Fuel Options

- Synthetic Petroleum
- Synthetic Diesel
- Kerosene
- Jet Fuel, JP-8, JP-54

Forward Operating Bases

Front Line Power Generation

- It is estimated that diesel used for power production on forward deployments can cost as much as $300 per gallon to deliver.
- Utilizing waste to generate power mitigates the risk and expense of delivering diesel to these sites.
- ***The ce25 operates with existing DoD reciprocating engines - protects existing investment.***
- Offset up to 92% of diesel consumption.

Improves soldiers health and sanitation conditions by eliminating burn pits.

Forward Deployment Sample Economics

1 year sample economics

Forward Deployment Sample Economics

Cost of Diesel per Gallon	**Diesel Reduction**
$300	75%
Gallons per 1MW/h	**Gallons per 1MW/h**
80	20
Cost per hour	**Cost per hour**
$24,000	$6,000
Hourly Cost Avoidance	
$18,000	

adaptiveARC Economics

Capex of ce25
$3,500,000
1Yr Opex
$625,000
Total 1 Year
$4,125,000

The Real Numbers

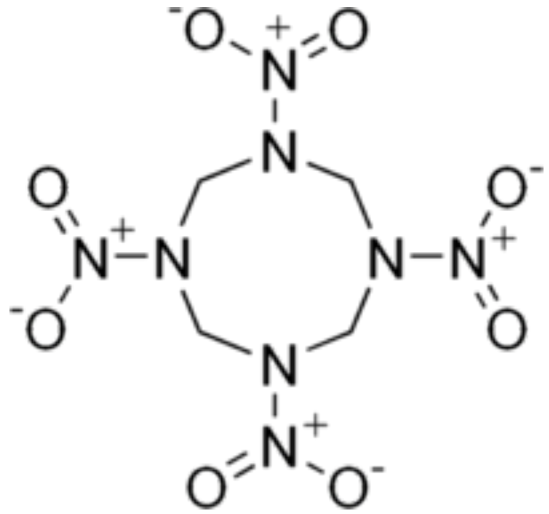
Hours to repay 1 year investment	Days to repay investment	Avoided costs daily	Avoided costs annually
229.17	9.55	$432,000	**$157,680,000**

Munitions Disposal
Simplifying Logistics

Munitions disposal is logistically complex, expensive and still requires transportation to the disposal site.

- The portable nature of the ce25 allows the system to deploy quickly on site, process munitions, then move to the next site without the logistical support or costs normally associated with munitions or chemical disposal.
- ce25 is suitable for chemical agents as well as explosives such as HMX and RDX.

Chemicals and munitions based on organics disassociate easily in a plasma process.



Active Bases

100% Sustainable. 100% Green. Achieve NetZERO Goals.

25 tons per day 500-1000kW output

- Start small and scale to needs
- Process multiple waste streams
- Base sustainability
- Reduce dependence on outside services
- Additional "green collar" jobs and technical positions.

Medical Waste

- The adaptiveARC ce25 can be operated on site at medical facilities, central collection facilities and infield emergency facilities. The high temperature environment insures total destruction of pathogenic and bio-hazardous waste streams.

Base Realignment and Closure (B.R.A.C.)
Remediation and Emissions Reduction

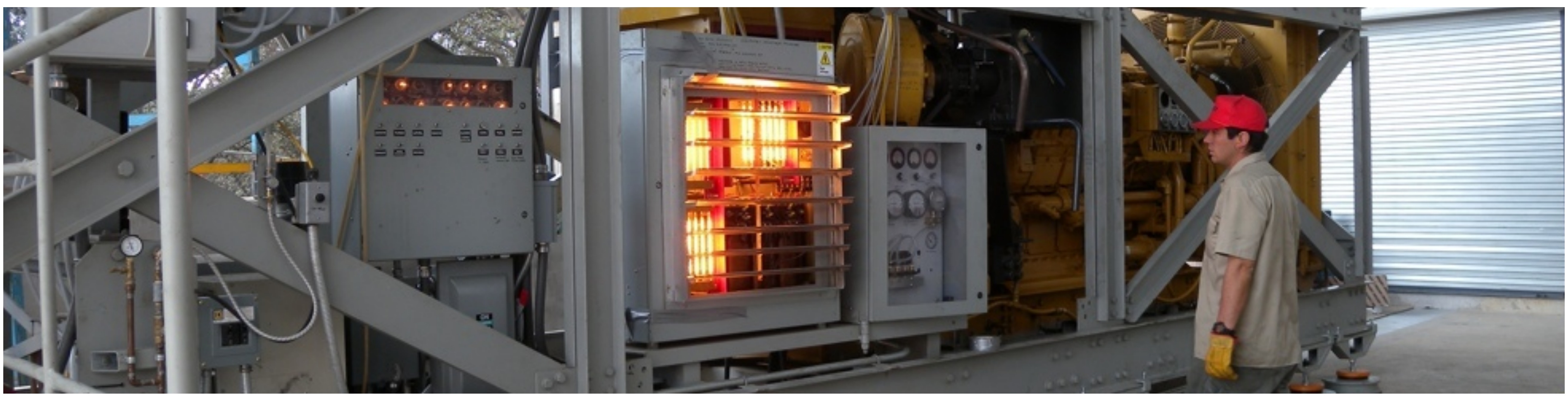
The ce25 can serve as a mobile detoxification system, which can be used in all brownfield development projects and all of the DoD's environmental cleanup activities.

- The ce25 can be transported from one site to another with fast delivery, set up and turn around time.
- This simplifies logistics and material handling / transport.
- Typical installation requires less than 48 hours.

adaptiveARC is more than clean energy, it's Energy That Cleans®.

adaptiveARC provides best in class solution by reversing environmental damages caused by waste and preventing new issues from occurring.

- Transform low-value, hazardous materials into high-value products for industries and communities around the world:
  - Creating renewable energy
  - Eliminating the toxic impact of waste
  - Providing air, land and water remediation



Partners and early adopters

nrg
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Thank You
Questions?

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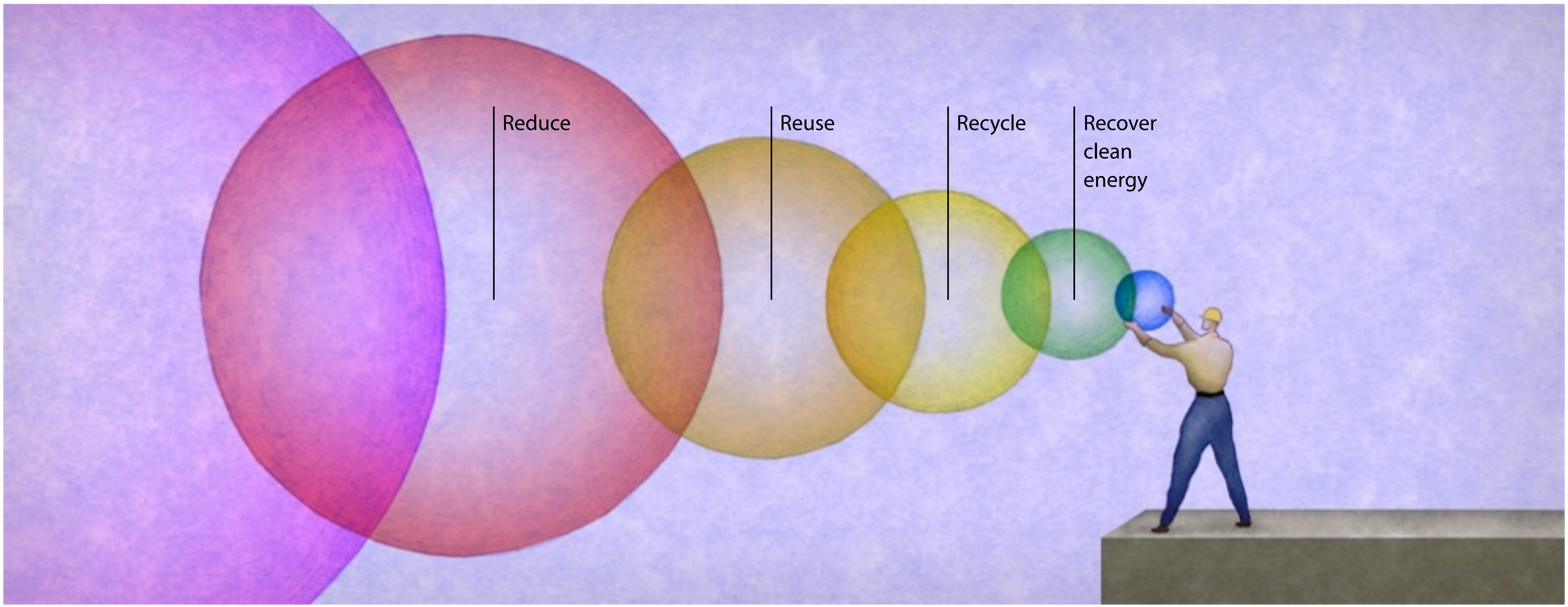


Issue

Garbage generated at forward bases could be a useful energy resource.

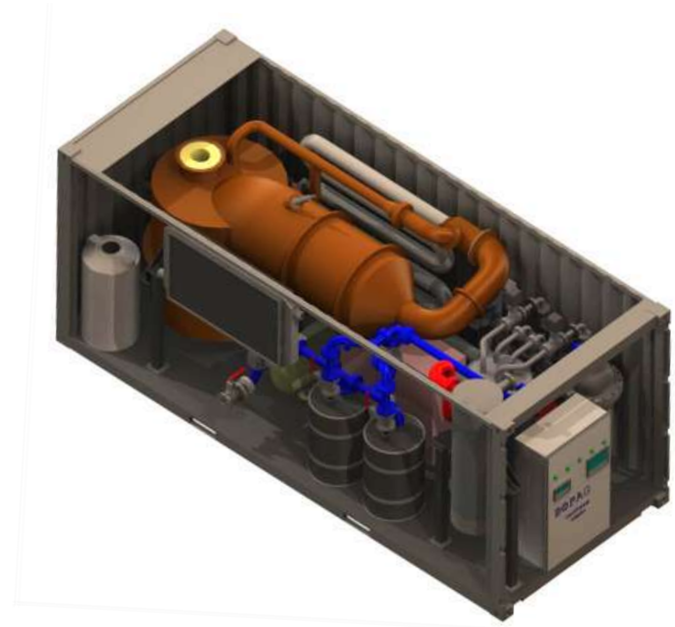
However the currently available technology:

Can destroy virtually any waste	But requires external power

Or

Can convert energy rich wastes to electricity	Requires sorting of the waste stream

Lockheed Martin Solution



Deployable Omnivorous Plasma Assisted Gasifier

Safely Destroys Nearly Any Kind of Waste

And

Generates Electricity

No Trash Sorting

No Utilities Required

Modular Waste to Energy: User Perspective

- Waste is an energy resource whose benefits are not being realized by both military and civilian customers

Military Benefits:

- Saving Fuel = Saving Money = Saving Lives
- Improved Force Protection
- Reduced Environmental Impact

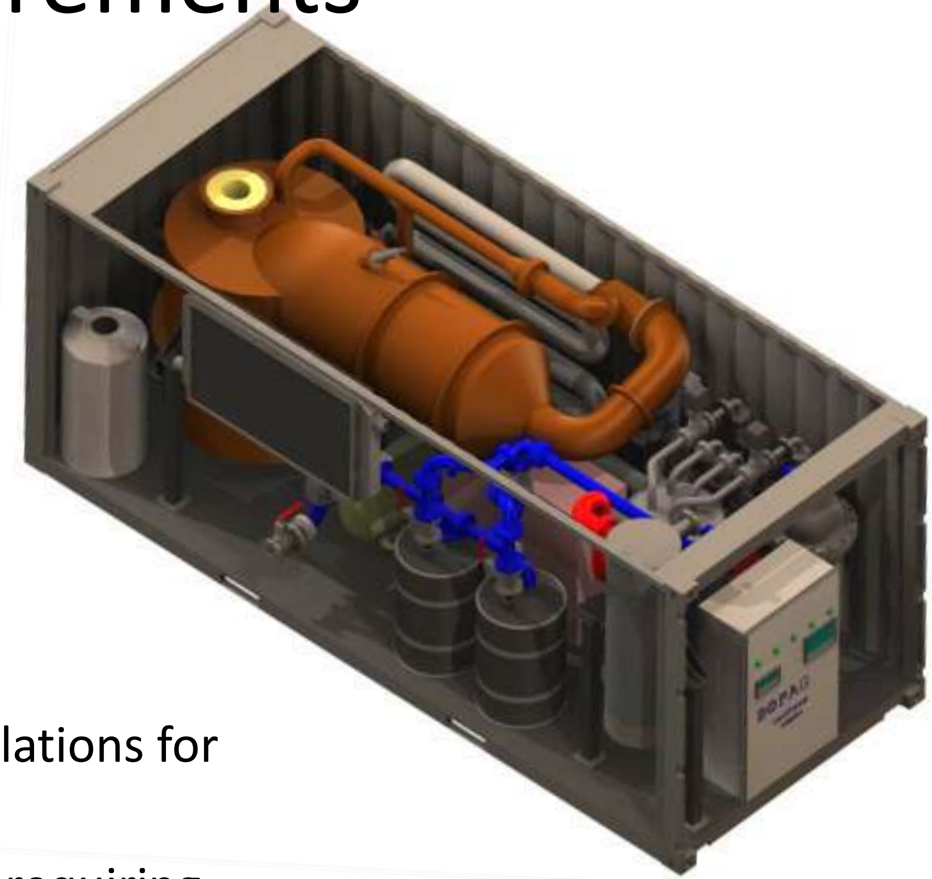
Hospital Benefits:

- Reduced Waste Fees
- Energy Cost Reductions
- Simplified Internal Operations

Multiple positive cash flows, simplified logistics, environmentally friendly

Accepts Waste From	Packaging and Shipping	Field Feeding	Construction and Demolition	Motor Pool Facilities	Medical Facilities	Sanitary Facilities
Captures Energy From	Wood, Cardboard, Plastic, Styrofoam	Paper, Cardboard, Plastic, Food	Wood, Plastics	Tires, Lubricants	Plastics, Biogenic Materials	Reduced Moisture Black-water Sludge
and Safely Remediates Entrained	Batteries, Metals	Metals and Glass	Metals, Glass, Gypsum Board, Insulation	Metal or Kevlar	Needles, Glass, Biohazard Materials	Contaminated Soil

DOPAG Requirements



1. 100% feedstock flexible – No waste sorting necessary
2. Net producer of energy
3. Non-hazardous by-products
4. 3.3 tons per day
5. 20 ft ISO container configuration (3)
6. Water neutral (self contained)
7. Hands-off operable
8. Meets applicable environmental regulations for operation at forward base
9. 30 days between major maintenance requiring shutdown
10. If fuel is required at start-up, must be JP-8 and diesel compliant

DOPAG Frequently Asked Questions

- Emissions?
  - The only air emissions come from the genset exhaust. The DOPAG converts the waste to synthesis gas, which is cleaned then fed to the air intake on a standard tactical quiet generator where it displaces fuel used to run the generator. Genset emissions are expected to be similar to emissions from the same genset running only on JP-8.
- The predicted energy balance is based on average waste. What if the waste has less energy?
  - The system is designed for high variation in waste composition. The energy balance will change as the feedstock composition changes. If the waste feedstock supply is very wet or otherwise low in energy the system can operate in a negative net energy mode.
- How much waste is required to keep the system operational?
  - The system is expected to have at least a 50% turn down capability. However, the system is designed to operate in a hot-reserve mode on a JP-8 fired pilot if there are gaps in feedstock availability.
- Can the system accept batteries?
  - Small batteries mixed into the waste stream are ok. The process is designed to safely handle small volumes of those materials. It is probably not advisable to destroy large batteries (like vehicle batteries) in this system. The materials are compatible, but safely loading and subsequent slagging of that volume of metal may be problematic.
- Are there other applications for this technology?
  - The system is suitable to applications where waste disposal costs are very high and/or energy costs are very high. On-site waste to energy at a hospital is economically attractive.

379: Response to Queries

Gabriel Jebb
VP Operations, adaptiveARC, Inc.

Defense and Intelligence Community Needs

1. **What types of waste and agricultural feedstock are available in your specific geographic areas of interest? What are those areas?**

   adaptiveARC is not limited by waste composition or agricultural fuel supplies. Currently we prefer to process hard to dispose of waste streams (e.g., medical waste, industrial waste, C&D) only because higher gate fees normally equally higher rates of return on the investment. We have also noticed that more caustic waste streams normally have a higher caloric value which lends itself to better power production.

   a. **What is the composition?**

      i. **What is the water content?**

         The ce25 is optimized for moisture contents of 20-35%. Higher moisture contents have been processed and we have tested the ce25 with feedstocks that have as high as 85% moisture (consistency of toothpaste). The ce25 can handle these higher moisture contents, but the energy output is reduced.

      ii. **What is the glass content?**

         Glass provides no energetic value for the ce25. Although glass is not an issue in terms of processing… it doesn't improve the overall energy balance. Our facility in Mexico currently operates on 1-2% glass by weight.

      iii. **What is the metal content?**

         The ce25 is a dry ash gasifier, meaning the system produces a commercial ash by product. Metals that enter the system are not slagged or encapsulated in the by product. They return in the ash as a metal, normally in a granular form.

      iv. **What is the caloric content?**

The lowest tested caloric value of fuel has been approximately 2000 kcal/kg. or 3600 btu/lb. That resulted in almost 500kw of continuous output. The highest caloric value was 10,400 kcal/kg. or 18,000 btu/lb. This resulted in much higher energy output (ie. over 1MW continuous), but lower throughput (about 450kg/hr).

b. Does feedstock include hazardous components?

Yes.

i. Does it include medical waste?

Yes

ii. Does it include radioactive waste?

No

iii. Does it include other toxic waste such as batteries, oil waste, or heavy metals?

Partially

c. What is the quantity available?

i. How much new feedstock is available per day?

The ce25 is capable of processing up to 25 tons per day or 9000 tons per year. The system will operate individually or in configurations of up to 10 systems (250 tons per day).

ii. How much would feedstock vary over 1 to 10 years?

N/A

iii. What is the quantity of stored feedstock such as in land fill?

adaptiveARC suggests that 3-5 days of fuel (waste material) is contained (stored) onsite.

d. What is being done with the waste now?

i. Is it being stored?

Landfill, or other disposal methods.

ii. Is it being destroyed?

N/A

e. What logistical concerns, if any, exist on transporting feedstock?

The logistical concerns are based on the feedstock. Medical waste requires special handling permits, as does hydrocarbon waste streams from refineries. Military munitions may require additional specific logistical requirements. No existing concerns in terms of the ce25's ability to process waste.

i. If collected, how is it collected and disposed of currently?

Normal haulers such as WMI, Allied/Republic, etc. haul the waste to existing landfill operations.

ii. Is hauling of the waste completed by a business operated under contract?

Depends on the customer.

iii. Is feedstock collected, distributed, or concentrated at one or more locations?

All of the above.

iv. Is it dumped on surface of soil or buried?

Normally buried in a landfill.

v. What sorting is or could be applied to feedstock?

adaptiveARC normally recommends MRF sorting/separating, etc. of material. This is not a requirement, but is normally considered the highest and best use of waste feedstocks.

vi. What drying could be applied to feedstock if the moisture content is in excess of 30% by volume?

The ce25 uses a pre-drying stage that is powered by exhaust produced by the reciprocating engine. The system diverts up to 30% of the exhaust to the "drying column" or pre-dryer.

2. What are the siting constraints on processing?

Normal permitting through local agencies.

a. Are there size, weight, or electrical power constraints?

No.

b. **Is there a suitable base on which to site the plant, which has a road or rail infrastructure now, as well as easy connectivity to power lines, water, and feedstock? How many acres are available? Must it be permitted by local government prior to plant construction and operation?**

N/A

c. **Is access available for delivering feedstock? What is the transport distance and means of transport? Is the delivery effectuated by public or private organizations?**

N/A

3. **What are the principal objectives for having the facility: eliminating waste; producing electrical power; producing liquid fuel; or all three?**

All three.

4. **What are the cost constraints for the technology, process, and products?**

a. **Must be process be profitable and economically competitive with other processes and products? What are your views on operational costs, process efficiency, and any by-products?**

adaptiveARC has focused specifically on the economic model of the technology. As a company we understand that "green bona fides" are not enough to introduce disruptive technologies to the marketplace. The technology must provide rates of returns to private investors that beat the marketplace (IRR of 20% over 10 years). O&M costs must be equal to or lower than traditional waste disposal (landfill), or less than $30 per ton. Power production must cost less than other renewables such as solar and wind, meaning we need to be profitable at less than $80Mwh. All byproducts must have commercial applications, such as the fly ash produced (which is a commodity).

b. **Must the process perform the mission at a reasonable cost? Is a reasonable cost the same as or less than current costs? Who bears these costs?**

The process must provide the same benefit at a lower cost; otherwise, there is no motivation to change from existing processing. adaptiveARC believes it can provide Mission Critical services such as power and waste remediation at a fraction of current costs. The deal structure will dictate who bears the weight of the cost.

c. **Is optimizing performance more important than cost?**

No

d. **Is the need just to destroy the waste without creating pollution?**

The need to destroy the waste with minimal pollution is a primary driver, but not more important than the costs associated with it. Again, if we cannot provide a "greener" solution at a lower price point, it doesn't make sense to change.

5. How will [bio] synthesis gas be utilized?

a. Flared or otherwise disposed?

Syngas can be flared in situations where power production is not viable or required. The gasifier is small enough were it can even be used as a afterburner system specifically to process effluents.

b. Fuel for diesel generator?

adaptiveARC technology requires a reciprocating engine (diesel engine) to drive the gasification process and combust the syngas. Any reciprocating engine can be retrofitted by adaptiveARC to use our syngas. This will protect existing DoD, DoE, etc. investment in traditional power generation. The syngas can offset up to 85% of fossil fuels normally combusted in a reciprocating engine.

c. Fuel for special purpose synthesis gas generator?

adaptiveARC has relationships with several manufacturers of engines that work with low BTU gas. Costs, efficiencies and reliability have not provided substantial increases over traditional recip engines. Most of these special generators are new to the marketplace and require heavy capital expenditures. adaptiveARC prefers to standardize on tried and tested technologies that already have widespread footprint in the industry.

d. Fuel for [a gas] turbine or engine generator?

Same as above.

e. Converted into JP-8 or other liquid hydrocarbon fuels, e.g., sustainable FT diesel fuel?

adaptiveARC has a relationship with SGE (Scandinavian Green Energy), the largest bio-fuels producer in Scandinavia. They have specific FT processes designed to operate with the adaptiveARC ce25 to catalyze synthetic diesel and Kerosene (for JP-8, JP-A, JP-B, etc.).

Session 2: Defense and Intelligence Community Experience

1. What feedstock have you processed?

MSW, MRF residuals, several types of coal, tires, multiple types of biomass, plastics, liquid hydrocarbons (refinery sludge), sewage sludge, carpet backing, off-gases and several types of industrial waste stream.

2. **What process have you used?**

   a. **What type of waste reception and storage? What type of shredder or pre-processing is done?**

      This depends on the specific location - adaptiveARC does not develop the entire facility or project; we simply provide the gasification island (core technology). We have several project developers we work with to develop the entire facility.

   b. **What type of waste drying system?**

      The ce25 comes with a pre-heater / dryer as part of the gasification island.

   c. **What type of plasma gasification reactor?**

      The ce25 is developed, engineered and manufactured 100% by adaptiveARC.

   d. **What type of synthesis gas cooling and heat recovery?**

      Two cooling towers are part of the ce25 system.

   e. **What type of synthesis gas cleaning? What emissions standards do you meet?**

      adaptiveARC has a proprietary gas cleaner than is part of the overall technology offering. The emissions produced by the ce25 are well below what the State of California allows. adaptiveARC is also compliant in EU regions in Europe.

   f. **What type of generators (diesel, turbine, other)? How well does it operate?**

      The ce25 is designed to work with Diesel-recip engines. New systems are paired with Caterpillar engines, either the 3512 or the 3516. Both engines are very popular with the DoD. adaptiveARC has also paired its process to Cummins, GE, Waukesha and Mann Engines.

   g. **What type of heat recovery?**

      Waste heat is recovered for the drying column / pre-dryer.

   h. **What are your wastes?**

      There is zero waste.

3. **What are your estimated/measured performance values?**

   Overall system effiiciency when measuring incoming BTU's to outgoing electricity is approximately 24%, which is on par with coal- or gas-fired power plants.

   a. **What is your average waste rate of processing?**

This is dependent on the feedstock. MSW 1.15 tons per hour, dry biomass 800kg per hour, industrial waste streams 600kg per hour. Higher BTU/lb. will decrease throughput but increase electrical production.

b. What is your average synthesis gas composition and rate or production?

Average syngas composition - 48% N_2, 21% CO, 9.5% CO_2, 14.5% H_2, 5% H_2O, 2% CH_4. Rate of production depends on feedstock between 55,000SCF/hr MSW and 110,000SCF/hr higher BTU fuel sources.

c. What is your average electrical power production? (What type of generator?)

The 3512 will max out at approximately 680kwe. The 3516 will max out at 1.1Mwe.

d. What other inputs are required?

Water, an alkaline agent (calcium or sodium), and a bit of propane or natural gas are needed to start the system.

e. What other outputs are generated (solid, liquid, gaseous wastes or materials)?

Outputs can be modified to customer/project needs, and include electricity, liquid fuels, syngas, ammonia and fly ash.

4. What is your process timeline?

a. What is your start-up time?

Startup time is 35-50 minutes, depending on feedstock and moisture content.

b. What is your shut-down time?

Shutdown is about 15 minutes, not including the ambient cool down of the processor, which lasts another 35-60 minutes.

c. What is your maintenance schedule?

22 hours on 2 hours downtime - 92% uptime.

5. What are your costs?

This depends on the deal structure. We can provide a turnkey solution, we can provide a BOO solution, BOT solution, lease options, etc.

a. What was your capital (acquisition) cost?

Turn-key sale, between \$3.2M and \$4.2M depending on feedstock pre-processing, power generation and system mobility requirements.

b. What is your feedstock cost?

We normally calculate feedstock as a revenue stream or a cost offset rather than a cost. We have not run into situations domestically where feedstock must be purchased. Some of our European deployments require purchasing of feedstock, but higher power purchase rates offset the cost of feedstock acquisition.

c. What are your operating labor hours and costs?

That depends on the size of the facility and the number of ce25s deployed. Labor costs are estimated at $12-18 per hour during operations, depending on geography. Fully burdened O&M costs are expected to be between $22-28 per hour.

d. What are your maintenance labor hours and costs?

We calculate maintenance hours and operational hours to have the same cost. adaptiveARC can walk you through a typical project *pro forma* to better describe costs of operations and maintenance.

6. What are the attributes and deficiencies?

a. What advantages have you observed over other types of gasifiers?

Mobility. The ce25 system takes less than 48 hours to deploy or move to a new location). We can move to the waste source rather than transport the waste to the facility.

Modularity. The system will work independently or in groups of up to 10 ce25's.

Scalability. We offer the ability to start with a single unit and scale to meet project demands without loss of original investment.

Flexibility. The ce25 has the ability to process multiple fuel types without having to reconfigure the system. Parasitic power requirements are less than 5% of overall power production.

b. What deficiencies or limitations have you observed?

Manual operation rather than automated operation.

c. What improvements do you envision?

Improvements in throughput and processing efficiency. Higher level of automation and PLC controls.

Session 3: Academic Perspectives

1. What are the principal "unknowns" with respect to plasma gasification?

No answer provided.

2. **What research is needed to improve plasma gasification, in particular with respect to compact, small-scale processing of waste and agricultural residue for synthesis gas production?**

   adaptiveARC research is primarily directed at improving the existing technology. Some of this is directed at engineering more modules for waste inputs or power outputs. Some of the science is directed at processing new feedstocks (ie. metals separation from contaminated soils). Better understanding of thermo-chemical processes in a plasma state is needed.

3. **How "green" is plasma gasification?**

   adaptiveARC believes that plasma gasification is the "greenest" option available for residual and hazardous waste disposals. Plasma offers a cheaper, more reliable heating source. Long term benefits are still unknown as our longest operational system only has 6 years of processing history.

   a. **How does it compare with other gasification technologies?**

      Plasma is the emerging technology in the gasification field and is the direction the industry is heading towards. Today, few companies provide end-to-end solutions for the entire gasification island. adaptiveARC manufactures all of the equipment from waste input to power output. Very few other companies own as much IP in plasma gasification as adaptiveARC. adaptiveARC has 10 patents on plasma torches, reactors, processes, etc. We have an additional 36 pieces of IP that we protect through trade secrets. The majority of plasma gasification providers are licensees of existing plasma technology rather than innovators in the plasma arena.

   b. **How does it compare with other low temperature processes for converting cellulose or other organic materials into gas or liquid fuels?**

      Plasma seems to provide a more diverse range of feedstocks to process with higher conversion efficiency than say anaerobic digestion.

   c. **What gas clean up is required?**

      adaptiveARC uses 12 Best Available Control Technologies (BACT) in the gas cleanup and emissions reduction process. This produces a very clean fuel source, with few emissions.

   d. **What are the limitations?**

      Some very complex chemical/metal species would be better suited to pyrolysis vs. gasification.

   e. **How could it be improved?**

Gasification technologies could be improved through greater cooperation between public agencies and institutions with private industry.

Session 4: Industry Perspectives

1. What is your approach to plasma gasification for waste to energy?

adaptiveARC has always viewed plasma gasification as a power production technology rather than a waste disposal technology. As such, the engineering of the ce25 focused on energy conservation within the process. This allows for a higher net output (95% of the power generated can be returned to the utility or customer.) adaptiveARC has developed several key innovations including lower power plasma torch designs, Regenerative Cleaning systems inside the gas cleanup, Cool Plasma™ Gasification as a process, etc.

a. What is your general process?

More detailed process diagrams can be provided. Fuel is essentially loaded into a pre-drying column that operates from waste heat created by the engine. The fuel material is then loaded into the gasification reactor where the molecular dissassociation occurs. The resulting syngas is then quenched, cooled, cleaned, water is removed, then piped to the engine through its air intake manifold. The syngas burns in the engine (offsetting diesel consumption), the exhaust is then reprocessed through the reactor increasing the thermal values but also cleaning the exhaust before releasing it to the atmosphere.

b. What is unique about your system and process?

adaptiveARC has approximately 40 key innovations that it has developed specifically for plasma gasification and power production.

c. If you use a plasma torch, is it AC or DC driven?

The adaptiveARC plasma torch is AC and utilizes a very specific (proprietary) pulsed power supply.

d. Is the torch used to gasify feedstock and/or clean up synthesis gas?

The torch provides some heat to the thermal/chemical reactions, but is primarily used to "polish" the syngas.

e. Describe your synthesis gas cooling and heat recovery system.

The gas cooling system is primarily an alkaline water quench that dissapates heat ambiently through the cooling towers. The heat is recovered and reintroduced to the gasifier through a series of heat exchangers and radiators.

f. Describe your synthesis gas cleaning system.

adaptiveARC has several proprietary systems in the gas cleanup. The basics are; polishing by the torches, acidic species are mitigated in the quench, bio-filters remove particulates and provide a highly absorbtive surface for metal removals. The water is centrifuged out of the gas. Additional particulate are scrubbed through a set of filters. The final cleaning is performed in the reciprocating engine which has combustion temperatures above 600C.

g. **What emissions standards does your system meet?**

The ce25 meets California emissions standards. It is also compliant with EU standards.

h. **Describe the generators (diesel, turbine, other) used in your system? What is their efficiency?**

Diesel - reciprocating engines. Caterpillar claims their engines are 36-38% efficient out of the box. The realistic efficiency is 32-34%. We are also testing the ce25 with spark ignited engines that utilize natural gas, like Waukesha, GE and Cummins.

i. **Describe your heat recovery system.**

Proprietary. Heat from the engine (exhaust) is routed back through the gasification process.

j. **What are your estimated and/or measured overall efficiency?**

Measured overall efficiency (incoming BTUs to outgoing kWs) is approximately 22-26% depending on fuel source (feedstock).

2. **What plasma gasification plants has your company designed, constructed, and/or operated?**

We have had a pilot facility in Monterrey, Mexico since 2005 and production facilities in Mexico City since 2010. New facilities are under construction in South Carolina, Brazil, England, Italy and Mexico. A total of 11 active systems will be in production by 1st quarter of 2012.

a. **What are the principal objectives of your system(s): eliminating waste; producing electrical power; producing liquid fuel; or all three?**

All three.

b. **When and where were they constructed (provide photos)?**

ce25s are manufactured in 3 locations (California, South Carolina, and England). Each of these manufacturing facilities are either owned or specifically designated for ce25 production. Photos can be provided of each location and systems under construction at your request.

c. What is the feedstock?

Feedstock in Monterrey, Mexico is freon and PCBs specifically. Mexico City is MRF (MSW) residuals. Brazil is medical waste. South Carolina is industrial waste streams and C&D. Facility in Italy is biomass and agricultural fuel sources. Facility in England is demonstration facility which tests and certifies feedstocks specifically for adaptiveARC.

i. What is the water content?

Moisture content ranges from 20-45%.

ii. What is the glass content?

Low 0-3%. Glass has a higher value as a recycled commodity. The ce25 can process glass, but it does not improve the energy balance.

iii. What is the metal content?

Depending on the facility, 3-8% by weight.

iv. What is the caloric content?

Depending on the facility and feedstock 3000 BTU/lb. - 11,000 BTU/lb.

v. What is the mass rate (tons/day) of processing?

The ce25 is designed to process 25 tons per day. Each facility is processing between 18-30 tons per day depending on feedstock and moisture content.

d. Can your system process hazardous components?

Yes

i. Does it include medical waste?

Yes

ii. Does it include radioactive waste?

No

iii. Does it include other toxic waste such as batteries, oil waste, or heavy metals?

No, Yes, Yes (partially)

e. Describe your waste reception and storage system.

Waste reception is normally a standard tip floor. High and low speed conveyors move the materials to staging (storage) areas for fuel preparation.

f. What type of pre-processing?

i. What type of shredder?

SSI

ii. What type of waste drying system?

Proprietary to adaptiveARC.

g. What is the current status of the system(s)?

Several systems are in production, new systems are being tested for deployment, and several systems are under construction.

h. What data is available (e.g. throughput, efficiency, etc.)?

Yes, lots of data, throughput, efficiency, power production, emissions profiles, gas profiles, etc.

3. What are your estimated/measured performance values?

4. What is your process timeline?

5. What are your costs?

For 3-5, see previous answers.

6. What are the siting constraints on your system?

a. Are there size, weight, or electrical power constraints?

No.

b. What base (ground) is required to site the plant?

Approximately 5000 sq. ft. per ce25

c. How many acres are required? Must it be permitted by local government prior to plant construction and operation?

See above. Yes we require air permits and may require EIR depending on location. We produce no waste water and the system is on wheels so it can be moved quickly.

d. Can your system be expanded?

Yes, it's modularized.

e. **Is your system portable?**

Yes.

f. **What is the size and weight of your system(s)?**

The entire ce25 system fits inside a standard conex container or on 40' flatbed trailer. Not including the engine, 35,000 lbs.

7. **How is synthesis gas utilized?**

Flared, fuel for engine, fuel offset for nat gas, fuel for FT system.

a. **Flared or otherwise disposed?**

b. **Fuel for diesel generator?**

c. **Fuel for special purpose synthesis gas generator?**

d. **Fuel for [a gas] turbine or engine generator?**

e. **Converted into JP-8 or other liquid hydrocarbon fuels, e.g., sustainable FT diesel fuel?**

Yes to all of these queries.

8. **What are your attributes and deficiencies?**

a. **What advantages have you observed over other types of gasifiers?**

b. **What deficiencies or limitations have you observed?**

c. **What improvements do you envision?**

d. **What research is needed to improve your capabilities?**

e. **Describe a system to handle waste streams of 1 to 5, 5 to 10, 10 to 20, 20 to 50, 50 to 100 tons/day and provide a net energy gain? What feedstock would be required for such systems (caloric content, water content, etc.)?**

The same ce25 can process waste in batch (less than 25 tons per day) or continuous (25 tons per day). Our ce25 system converts 25 tons per day into a continuous 500kW – 1,000kW of clean renewable energy. Our systems are portable, modular and scalable and can be designed and configured to handle waste streams from 25 – 250 tons per day.

We need a minimum caloric value of 3500 BTUs/lb. to power the smaller cat engines. Water content can be as high as 55% but energy output will diminish with low BTU fuel sources.

379: Response to Queries

PyroGenesis Canada

Session 1: Defense and Intelligence Community Needs

1. **What types of waste and agricultural feedstock are available in your specific geographic areas of interest? What are those areas?**

   PCI does not have a specific geographic area of interest. Our plasma waste-to-energy technology can process all sorts of wastes and feedstock, including municipal solid waste, agricultural waste, hazardous waste, biomedical waste, etc.

   a. **What is the composition?**

      i. **What is the water content?**

         No technical limitation.

      ii. **What is the glass content?**

         No limitation.

      iii. **What is the metal content?**

         No limitation.

      iv. **What is the caloric content?**

         No technical limitation.

   b. **Does feedstock include hazardous components?**

      Yes.

      i. **Does it include medical waste?**

         Yes.

      ii. **Does it include radioactive waste?**

         Yes, at a dedicated facility only.

      iii. **Does it include other toxic waste such as batteries, oil waste, or heavy metals?**

         Yes.

c. **What is the quantity available?**

We are not responsible for sourcing feedstock.

d. **What is being done with the waste now?**

At Hurlburt Field, it is being processed.

i. **Is it being stored?**

For 1-2 days max.

ii. **Is it being destroyed?**

Yes.

e. **What logistical concerns, if any, exist on transporting feedstock?**

Not responsible for sourcing or transporting feedstock.

v. **What sorting is or could be applied to feedstock?**

Large metal objects are removed from feed to prevent unnecessary damage to the shredder.

vi. **What drying could be applied to feedstock if the moisture content is in excess of 30% by volume?**

Heat from processing can be used to improve energy balance, but is not a technical requirement.

2. **What are the siting constraints on processing?**

No constraints.

3. **What are the principal objectives for having facility? Eliminating waste, producing electrical power, producing liquid fuel, or all three?**

All three.

4. **What are the cost constraints for the technology, process, and products?**

We believe that these questions are directed to potential end-users.

5. **How will [bio] synthesis gas be utilized?**

a. **Flared or otherwise disposed?**

Yes, this is our back-up if the engine is not available.

b. Fuel for diesel generator?

Possible as a dual-fuel concept.

c. Fuel for special purpose synthesis gas generator?

Possible.

d. Fuel for [a gas] turbine or engine generator?

Yes, this is our current practice.

e. Converted into JP-8 or other liquid hydrocarbon fuels, e.g., sustainable FT diesel fuel?

Possible.

Session 2: Defense and Intelligence Community Experience

1. What feedstock have you processed?

MSW, Hazardous Waste, Biomedical Waste

2. What process have you used?

The answers to this query refer to the AFSOC Hurlburt Field installation.

a. What type of waste reception and storage?

Waste is dumped from a truck directly onto a tipping floor. Storage on this floor is for a maximum of 4 days. Large metal objects are manually removed and the waste is then fed, unsorted, to a shredder. Hazardous and biomedical waste is received in small boxes, which are fed directly to the furnace in a dedicated box feeder. Liquid wastes (sludge oil) have been fed directly into our PAWDS technology in Montreal.

b. What type of waste drying system?

We have no drying system.

c. What type of plasma gasification reactor?

PyroGenesis two-stage, proprietary Plasma Resource Recovery System (PRRS) and PyroGenesis' patented Plasma Arc Waste Destruction System (PAWDS).

d. What type of synthesis gas cooling and heat recovery?

Direct water spray in a quench to prevent dioxin and furan formation. Currently, the heat is not recovered, though heat recovery mechanisms can easily be adapted to the technology.

e. What type of synthesis gas cleaning?

This is dependent on the feedstock. At Hurburt Field, there is an acid gas scrubber (packed column), an H_2S scrubber (catalyst adsorption – 3rd party regeneration), activated carbon filter for volatile metals (3rd party regeneration), knock-out pots for humidity carry-over, HEPA filters for particulate.

f. What emissions standards do you meet?

Florida EPA.

g. What type of generators (diesel, turbine, other)? How well does it operate?

GE Jenbacher internal combustion engine – it operates well.

h. What type of heat recovery?

Currently, the heat is not recovered, though heat recovery mechanisms can easily be adapted to the technology.

i. What are your wastes?

The inorganic fraction of the feedstock forms a vitrified slag, an inert, glassy rock which can be used for aggregate and other construction materials

3. What are your estimated/measured performance values?

a. What is your average waste rate of processing?

PRRS is designed for 10.5 metric tons per day but is very scalable for both smaller and larger capacity requirements. The PAWDS processes 5 tons per day and is scalable up to 15 tons per day.

b. What is your average synthesis gas composition and rate or production?

The 10.5 TPD PRRS is designed for 488 scfm at the following composition: 18% CO, 21% H_2, 6% CO_2, 6% H_2O, balance N_2.

c. What is your average electrical power production?

420 kW

d. What other inputs are required?

Consumables such as sodium hydroxide for acid gas scrubbing, makeup water for gas cooling, electrodes for plasma torches and graphite rods for the plasma reactor.

e. What other outputs are generated (solid, liquid, gaseous wastes or materials)?

Inert vitrified slag, metal ingot, catalyst is sent back to the supplier for sulfur recovery and the spent activated carbon is sent back to the supplier for volatile metal recovery.

4. What is your process timeline?

a. What is your start-up time?

From a cold furnace the PRRS can be ready to process waste within 24 to 36 hours. Normally the system is kept in idle mode during routine maintenance to ensure 85% availability. The PAWDS can be started up in just a few minutes.

b. What is your shut-down time?

The system can be shut down within a few minutes in an emergency situation, and in less than 30 minutes to prepare for routine maintenance. If maintenance is required on the furnace, then 12 to 24 hours are required for cool-down. The PAWDS can be shut down within just a few minutes.

c. What is your maintenance schedule?

With regards to the main items, the furnace is tapped daily to remove slag. The electrodes are installed daily. The plasma torch needs to be maintained after 600 hours of operation, though a spare torch is installed immediately to minimize the shutdown time. The refractory in the crucible of the furnace would need to be replaced once every year, though a spare crucible can be used in this instance.

5. What are your costs?

a. What was your capital (acquisition) cost?

$7.4M

b. What is your feedstock cost?

No cost.

c. What are your operating labor hours and costs?

Because of the significant amounts of large metal objects, one trash sorter has been hired to remove these during the day shift. If a more robust shredder were procured then the typical labor requirements would involve one operator and one helper per 12 hour shift. The plant is designed to operate 24 hours a day, 7 days a week. These individual would be responsible for maintaining the system as well.

d. What are your maintenance labor hours and costs?

Most maintenance is performed by the operating staff. From a budgeting perspective, one additional person for 20 hours per week is sufficient.

6. What are the attributes and deficiencies?

a. What advantages have you observed over other types of gasifiers?

Minimal conditioning of the waste is required compared to other lower temperature techniques, which require a consistent composition.

b. What deficiencies or limitations have you observed?

Current shredding approach is not robust enough to deal with specific base requirements. Additional labor is being used to remove large metal objects.

c. What improvements do you envision?

An improved front-end that would more efficiently remove the bulky metal waste that does not necessarily need to be fed to process. This will reduce the labor requirement.

Session 3: Academic Perspectives –

1. What are the principal "unknowns" with respect to plasma gasification?

a. Can it be modeled with high fidelity?

Not applicable to PyroGenesis.

b. Can it be simulated with high fidelity?

Not applicable to PyroGenesis.

c. What are the scaling limits to low and high volume processing?

PyroGenesis PRRS technology is available from 2 to 100 tons per day.

2. What research is needed to improve plasma gasification, in particular with respect to compact, small-scale processing of waste and agricultural residue for synthesis gas production?

Increasing overall energy efficiencies; capturing and maximizing waste heat for electricity production (ex. organic rankine cycle).

3. How "green" is plasma gasification?

a. How does it compare with other gasification technologies?

No fossil fuels are consumed in the process and there is no requirement for the addition of coal, tires or other highly energetic wastes to accomplish the reactions.

b. How does it compare with other low temperature processes for converting cellulose or other organic materials into gas or liquid fuels?

If you have a consistent feedstock, then the lower temperature processes may have improved energy efficiency. However, when you have a variable or hazardous feedstock, plasma gasification is much more robust in processing these wastes and there are no secondary wastes produced.

c. What gas cleanup is required?

See 2.2.

d. What are the limitations?

None.

Session 4: Industry Perspectives

1. What is your approach to plasma gasification for waste to energy?

a. What is your general process?

PyroGenesis has two distinct product offerings in the waste to energy sector. Our Plasma Arc Waste Destruction System (PAWDS) is designed to either treat combustible waste on board ships or be used as a mobile system for land based applications while our Plasma Resource Recovery System (PRRS) is designed to treat a range of industrial, hazardous, clinical and municipal waste streams. The patented PRRS converts both hazardous and non-hazardous waste into energy and a vitrified rock “slag” which can subsequently be used as a construction material. PRRS combines the advanced processes of gasification and vitrification in an efficient two stage plasma arc system with the second stage taking advantage of the US Navy’s patented plasma-fired eductor as the syngas polishing step. PAWDS can also be adapted as mobile land-based unit and include heat recovery and/or electricity production.

The PRRS process works as follows.

- Waste is shredded and fed to a primary gasification furnace, where graphite electrodes create the plasma arc to initially gasify the waste.
- Operating in conditions over 2900$_{o}$F, the inorganic fraction of the waste will settle in the furnace in two layers, a metallic layer and a glassy one. Both materials are removed periodically from the furnace.
- The dirty syngas, which will also contain soots, tars, and some hydrocarbon carryover, pass though the secondary gasification chamber, which is fired by an air plasma torch and the patented eductor.
- Operating at over 2000$_{o}$F, the remaining hydrocarbons are cracked, to complete the syngas transformation.

- The gas, which will still contain acid, hydrogen sulfide, volatile metals and some particulate, is then immediately quenched down to under 180_{o}F with fresh water to prevent dioxin and furan formation.
- Various abatement processes are then used to clean the syngas.
- This gas can then be fed to a flare or an internal combustion engine to produce electricity.

The mobile PAWDS-ER works as follows.

- Unsorted Mixed Solid Waste (MSW) is fed to the shredder, where its size is reduced.
- The shredded waste is then conveyed to a hopper-mixer where it is then pneumatically fed to a mill which transforms it into a lint-like substance.
- The milled waste is then introduced into the plasma fired educator (gasifier) where it is converted to a syngas.
- The syngas is then rapidly cooled to below 100_{o}C in order to prevent the formation of dioxins and furans.
- The gas then passes through a Venturi scrubber to remove particulate matter. A packed column is used to remove acid gases. A bed of iron oxide catalyst is used to remove H_2S from the gas stream. A HEPA filter is used to remove fine particles from the gas stream.
- At this point the syngas is further cooled to remove moisture from the gas and then passes through an activated carbon filter to remove any volatile metals from the syngas. The whole system is kept under negative pressure by an induced draft (ID) fan.
- At this point, the gas can either be fed to a thermal oxidizer to combust the syngas and energy recovered using an Organic Rankine Cycle or alternatively the syngas can be fed into a dual fuel diesel engine to produce electricity and hot water.

b. What is unique about your system and process?

The PRRS uses the efficiency of graphite arc electrode in the first gasification step, combined with the polishing capabilities of our air plasma torch (with the longest life electrodes in the industry) in the secondary gasification step to efficiently transform variable waste streams into products. The PAWDS uses a mill to grind the waste making it extremely compact. Since there ise no refractory in the PAWDS it can be started up and shut down in just a few minutes. The entire system is highly automated with only one button to start and shut down the system.

c. If you use a plasma torch, is it AC or DC driven?

DC.

d. Is the torch used to gasify feedstock and/or clean up synthesis gas?

Both.

e. Describe your synthesis gas cooling and heat recovery system.

Currently water is directly injected into the hot stream, which does most of the cooling. In a larger scale process, a heat exchanger with a thermal fluid can be used to capture this heat.

f. Describe your synthesis gas cleaning system.

The unit operations include an acid scrubber (packed column), an H_2S scrubber (catalyst adsorption – 3rd party regeneration), activated carbon filter for volatile metals (3rd party regeneration), knock-out pots for humidity carry-over, HEPA filters for particulate.

g. What emissions standards does your system meet?

Florida EPA.

h. Describe the generators (diesel, turbine, other) used in your system. What is their efficiency?

GE Jenbacher Internal Combustion Engine – 35-42% efficiency.

i. Describe your heat recovery system.

There is no heat recovery at Hurlburt Field.

j. What are your estimated and/or measured overall efficiency?

With an organic rankine cycle, up to 45% of the energy can be recovered.

2. What plasma gasification plants has your company designed, constructed, and/or operated?

PRRS

- AFSOC, Hurlburt Field, Florida – 10.5 TPD Transportable Plasma Waste-to-Energy Plant
- 2 TPD Pilot Plant – Montreal Quebec
- 2 TPD Testing Facility – Technical University of Athens, Greece

PAWDS

- USS Gerald R. Ford Supercarrier (CVN-78) – Factory Acceptance Testing in Montreal completed in early 2011. The system was then dismantled and refurbished for shipment to Newport News Shipbuilding.

- Engineering Development Model (EDM), built in 2003 and still in operation in Montreal (US Gov't Property).

- Advanced Technology Demonstration (ATD) unit, operated from 1999-2001 in Montreal (dismantled).

a. What are the principal objectives of your system(s)?

i. Eliminating waste?

Yes

ii. Producing electrical power?

Yes (though secondary).

iii. Producing liquid fuel?

No but could be a possibility.

b. When and where were they constructed (provide photos)?

The AFSOC facility was completed at the end of 2010, and is currently in operation. The Ford PAWDS was assembled for factory acceptance testing in early 2011. It was then dismantled, refurbished, and shipped in October 2011 to the Huntington Ingalls Newport News Shipyard for eventual installation on the USS Ford. See the final section of this file for photos.

c. What is the feedstock?

MSW, biomedical, hazardous waste.

v. What is the mass rate (tons/day) of processing?

11.6 short tons per day.

d. Can your system process hazardous components?

Yes.

i. Does it include medical waste?

Yes.

ii. Does it include radioactive waste?

AFSOC – No, though a dedicated PRRS can do this.

iii. **Does it include other toxic waste such as batteries, oil waste, or heavy metals?**

Yes.

e. **Describe your waste reception and storage system.**

Garbage trucks dump the waste into a receiving area. Biomedical and hazardous waste is generally received in box form and stored away from traffic areas.

f. **What type of pre-processing?**

Currently, labor is employed to remove bulky metal items which could damage the shredder. A more robust front-end is planned.

i. **What type of shredder?**

Vecoplan Waste Grinder.

ii. **What type of waste drying system?**

None.

g. **What is the current status of the system(s)?**

Operational.

h. **What data is available (e.g. throughput, efficiency, etc.)?**

Specific data can be made available upon request.

3. **What are your estimated/measured performance values?**

a. **What is your average waste rate of processing?**

Designed for 10.5 metric tons per day.

b. **What is your average synthesis gas composition and rate or production?**

Designed for 488 scfm at the following composition: 18% CO, 21% H_2, 6% CO_2, 6% H_2O, balance N_2.

c. **What is your average electrical power production?**

420 kW

d. **What other inputs are required?**

None.

e. What other outputs are generated (solid, liquid, gaseous wastes or materials)?

Inert vitrified slag, metal ingot, catalyst to recover sulfur, activated carbon to recover metals.

4. What is your process timeline?

a. What is your start-up time?

From a cold furnace, startup takes 24-36 hours. Otherwise, the system is normally kept in idle during routine maintenance.

b. What is your shut-down time?

A few minutes for emergencies, or less than 30 minutes for routine maintenance (not including furnace maintenance).

c. What is your maintenance schedule?

With regards to the main items, the furnace is tapped daily to remove slag. The electrodes are installed daily. The plasma torch needs to be maintained after 400 hours of operation, though a spare torch is installed immediately to minimize the shutdown time. The refractory in the crucible of the furnace would need to be replaced once every year, though a spare crucible can be used in this instance.

5. What are your costs?

a. What was your capital (acquisition) cost?

$7.4M

b. What is your feedstock cost?

No cost.

c. What are your operating labor hours and costs?

Once front-end upgrades are installed, the labor will be one operator and one helper per 12 hour shift, in a plant operating 24 hours a day, 7 days a week.

d. What are your maintenance labor hours and costs?

Most maintenance is performed by the operating staff. From a budgeting perspective, one additional person, 20 hours per week is sufficient.

6. What are the siting constraints on your system?

a. **Are there size, weight, or electrical power constraints?**

No.

b. **What base (ground) is required to site the plant?**

c. **How many acres are required?**

Approximate: 10.5 TPD – 0.5 acres, 100 TPD – 3 acres (Greenfield site).

d. **Must it be permitted by local government prior to plant construction and operation?**

Yes.

e. **Can your system be expanded?**

Additional modules can be adapted to the process.

f. **Is your system portable?**

PAWDS can be rendered portable, encompassing no more than 3 maritime containers. PRRS is transportable with ~14 containers.

g. **What is the size and weight of your system(s)?**

Depends on the capacity.

7. **How is synthesis gas utilized?**

a. **Flared or otherwise disposed?**

Yes, this is our back-up if the engine is not available.

b. **Fuel for diesel generator?**

Possible.

c. **Fuel for special purpose synthesis gas generator?**

Possible.

d. **Fuel for [a gas] turbine or engine generator?**

Yes, this is our current practice.

e. **Converted into JP-8 or other liquid hydrocarbon fuels, e.g., sustainable FT diesel fuel?**

Possible.

8. What are your attributes and deficiencies?

a. What advantages have you observed over other types of gasifiers?

Minimal conditioning of the waste is required compared to other lower temperature techniques, which require a consistent composition.

b. What deficiencies or limitations have you observed?

Current shredding approach not robust enough to deal with specific base requirements. Additional labor is being used to sort waste.

c. What improvements do you envision?

An improved front-end to more efficiently remove bulky metal waste which does not necessarily need to be fed to process. This will reduce the labor requirement.

d. What research is needed to improve your capabilities?

The PRRS is designed to be a very scalable technology. The 10.5 TPD AFSOC facility is the largest system built to date. PCI is seeking opportunities to demonstrate the technology’s capabilities at a larger scale (25-100 TPD). The PAWDS technology has been designed for marine applications but could be demonstrated as a mobile land-based unit with energy recovery.

e. Describe a system to handle waste streams of 1 to 5, 5 to 10, 10 to 20, 20 to 50, 50 to 100 tons/day and provide a net energy gain? What feedstock would be required for such systems (caloric content, water content, etc.)?

Lower temperature gasification processes are appropriate for biomass applications where there is a consistent feed composition, and the feedstock is non-hazardous. Plasma deals well with the varying compositions experience with MSW, and operates at appropriate temperatures for hazardous and biomedical waste.

From an energy perspective, for MSW, we expect to see a net surplus of electricity at capacities greater than 20 TPD. In the 5-20 TPD range, the processes are more or less self-sufficient in their energy requirements.

In terms of composition, the more metal and water that is present in the process, the less energy efficient the process will be. However, plasma gasification is robust enough to deal well with variations in metal and water content.

Photos of PyroGenesis Canada Plasma Gasification Facilities

Figure 1. AFSOC PRRS - Primary and Secondary Gasification Steps.

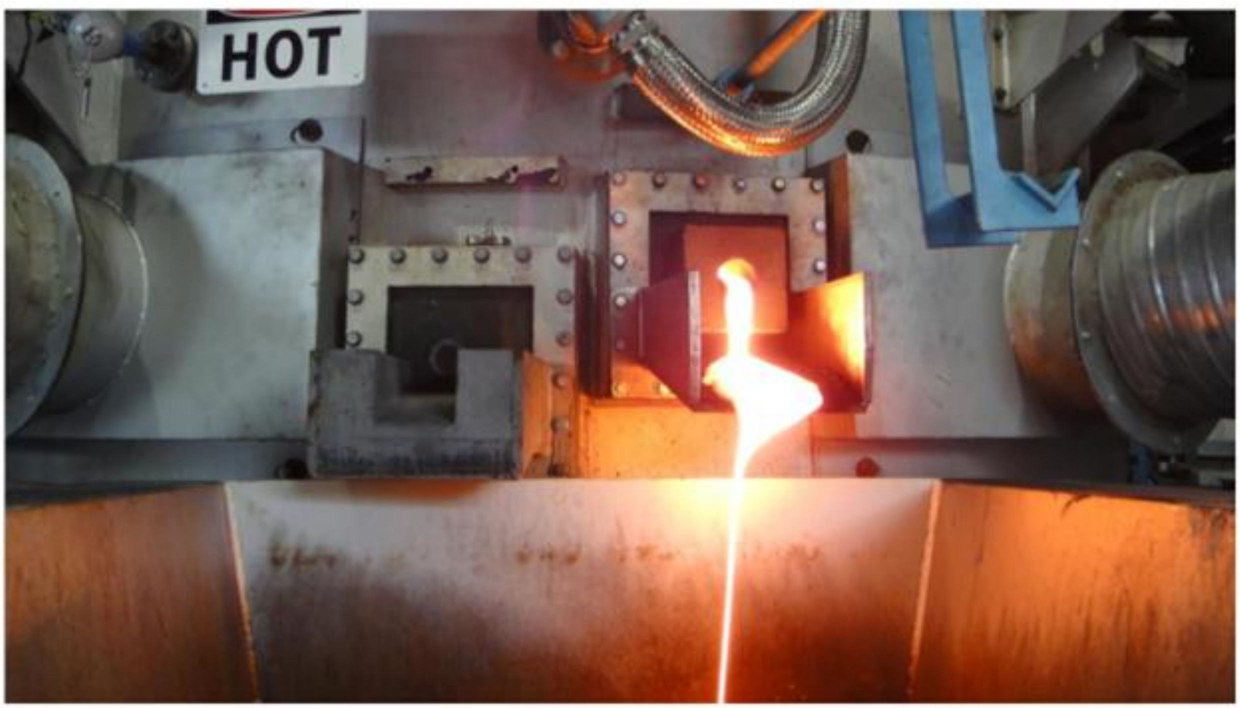


Figure 2. Vitrified Slag pouring from Primary Gasification Furnace.

Figure 3. Ribbon Cutting Ceremony - Hurlburt Field, Florida - April 26, 2011.

Figure 4. PAWDS for USS Gerald R. Ford supercarrier undergoing factory acceptance testing in Montreal.

379: Response to Queries

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N.B.: All comments represent the personal viewpoint of the author at time of submission in September 2011, and do not imply official position or endorsement of the US Army, US Army Logistics Innovation Agency, or any other organization.

Defense and Intelligence Community Needs

1. **What types of waste and agricultural feedstock are available in your specific geographic areas of interest? What are those areas?**

   Based on many conversations with sustainment community SMEs and analysis of previous studies, I believe Army and other Services do not have optimal or current operational waste stream data, especially for the purposes of informing WTE system requirements and design.

   US Army Logistics Innovation Agency (LIA) has obtained funding for a waste stream assessment project involving conducting waste characterization studies at a sample of medium-large (>3000 resident personnel) contingency bases in Afghanistan to inform Army Central (ARCENT) development of requirements for WTE systems.

   In support of the Contingency Base Waste Stream Analysis Project, an LIA project team conducted waste characterization studies at four contingency bases in Afghanistan and one in Kuwait in Feb-Mar 2012. Data analysis ongoing with final report expected by Sep 2012.

2. **What are the siting constraints on processing?**

   a. **Are there size, weight, or electrical power constraints?**

      From a logistics perspective, the Defense Community prefers WTE systems that can power themselves requiring no or minimal fuel or other external resources to operate, and systems that are containerized and easy to maintain (preferable by non-engineer operators) in an austere forward base. WTE systems should not increase the site logistics

requirements, especially for power, fuel, and/or water. Ideally, WTE systems should be able to export significant amounts of electricity to their site.

b. **Is there a suitable base on which to site the plant, which has a road or rail infrastructure now, as well as easy connectivity to power lines, water, and feedstock? How many acres are available? Must it be permitted by local government prior to plant construction and operation?**

Permitting may or may not be required depending on the specific location, but it is recommended that military WTE systems be capable of operating in austere environments drawing no more than minimal external resources (e.g. <5 gallons of JP-8 fuel to start up, etc).

c. **Is access available for delivering feedstock? What is the transport distance and means of transport? Is the delivery effectuated by public or private organizations?**

For use of WTE within in a forward base, transport distance should be minimal, either by military personnel or support contractors.

3. **What are the principal objectives for having facility?**

a. **Eliminating waste?**

1st priority given power generation limitations of current technology, efficiency at eliminating waste is expected of any system under consideration. Safe, efficient, and effective disposal of waste in forward bases is an important challenge.

b. **Producing electrical power?**

2nd priority given current technology; producing electric power is extremely desirable, but at minimum any WTE system should be able to power itself and not rely on external inputs. Significant production of exportable electrical power that would enable the Army to require/operate fewer generators reducing fuel consumption and associated logistics requirements in an operational setting would be a great achievement.

c. **Producing liquid fuel?**

Low priority (unless system could efficiently produce JP-8) —to my knowledge, Army does not currently use alternative liquid fuels extensively.

4. **What are the cost constraints for the technology, process, and products?**

a. **Must be process be profitable and economically competitive with other processes and products? What are your views on operational costs, process efficiency, and any by-products?**

I personally am interested in considering whether it would be more cost effective in the near- to mid-term for the Army (and other Services/organizations) to procure emission-

controlled “safe and clean” incinerators rather than WTE systems to better handle waste management problems. The small, transportable systems (capacity <10 tons/day) I am familiar with have difficulty in producing significant amounts of exportable power relative to their size and cost. If small WTE systems for the foreseeable future are in operation little more than very expensive incinerators, why shouldn’t the operational sustainment community consider more investment in advanced incinerators which have potential to reduce the waste burden without the added cost/complexity of energy recovery?

b. Must the process perform the mission at a reasonable cost? Is a reasonable cost the same as or less than current costs? Who bears these costs?

c. Is optimizing performance more important than cost?

No for R&D purposes, but for major investment such as acquisition and fielding, I believe cost of WTE systems should be evaluated relative to their competitors (e.g. clean incinerators) and their intended use (eliminate waste vs producing significant amounts of exportable energy). WTE as a concept briefs well, but if most current small WTE systems are at best capable of eliminating waste and producing enough energy to power themselves, is it fair to classify them as WTE with their larger counterparts (~>50TPD facilities)? Note discussion of common misperception of all WTE systems as energy exporters below.

d. Is the need just to destroy the waste without creating pollution?

All small, transportable WTE systems I am familiar with are at best effective in safely eliminating waste and rarely are an effective and/or significant exportable energy producer relative to cost, size, and complexity. Whether or not the question’s stated need is “the need” is worthy of discussion, but based on my understanding of the state of current small WTE technology, it is the most realistic expectation. In contrast from my experience, decision-makers and others more familiar with the concept of WTE rather than the state of the technology are most interested in the “E” aspect, often sharing a perception that all WTE systems are generally significant producers of exportable energy. However, current state seems to be that large facilities are more successful at relatively cost effective exportable energy production, while small WTE systems at best could be effective in the superficially less interesting “W” as waste eliminators rather than the more attractive “E” as exportable energy producers.

5. How will [bio] synthesis gas be utilized?

a. Flared or otherwise disposed?

b. Fuel for diesel generator?

c. Fuel for special purpose synthesis gas generator?

d. Fuel for [a gas] turbine or engine generator?

e. Converted into JP-8 or other liquid hydrocarbon fuels, e.g., sustainable FT diesel fuel?

B and D seem better immediate options, assuming current generators can run effectively on syngas. E is very interesting, but would be concerned about how well the conversion process would actually work and how much operator effort/additional complex equipment would be required.

Session 2: Defense and Intelligence Community Experience

The Logistics Innovation Agency has not demonstrated a Waste-to-Energy system, but would be interested to hear about participant experiences and comments on what, if any, specific requirements they have developed for such systems.

379: Response to Queries

Roland S. Besser
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Academic Perspectives

1. **What are the principal "unknowns" with respect to plasma gasification? (Can it be modeled with high fidelity? Can it be simulated with high fidelity? What are the scaling limits to low and high volume processing?)**

   Based on the literature of plasma gasification (PG) which dates back at least a few decades, the science that underpins plasma formation in a torch reactor is well established. This is consistent with the existence of an infrastructure supporting the commercial market for PG technology that dates back to the 1970s at Westinghouse. Interest in PG declined in the US—not surprising given low fossil fuel costs—and PG captured more interest globally than domestically. However, the US-based companies active in this area appear to be well-positioned for opportunities in the current climate in which the need for alternative energy sources is a foregone conclusion.

   In addition to work to understand plasma formation, there has been significant work in chemical conversion of several organic species that are particularly important in the waste and energy production application, as reflected in both the scientific literature and the patent literature. However, more research which could detail the manner in which specific species respond to the PG conditions would be helpful in identifying limitations posed by various feedstocks, and could serve to provide additional guidance for those seeking to optimize the approach for various applications.

   Regarding modeling and simulation: although these terms are usually regarded as synonymous, I will take modeling to refer to the application of the basic phenomenological understanding of the physics- and chemistry-based mechanisms at work in the gasification environment to yield a model that reasonably predicts observed experimental behavior. Simulation will be taken to mean the ability to create a model of an entire process wherein the components of the process, such as gasifiers, heat exchangers, etc. are regarded as "black boxes" and which conveys their functionality without regard necessarily to the intricacies of the mechanisms operating internally.

With regard to modeling, the state of advanced modeling of reactive plasmas is such that commercial simulators, e.g., COMSOL (Comsol, Inc.) offers an electromagnetic module that can run with a chemical reaction engineering module to successfully simulate devices such as plasma chemical vapor deposition reactors and plasma etchers in three dimensions. Although a plasma torch is a significantly different reactor, it is a fair conclusion that implementing tools such as these on PG is entirely possible, especially given the ability of these programs to accept user-generated custom codes.

Similarly, the implementation of PG in a process simulator like Aspen (Aspentech, Inc.), seems like a reasonably straightforward undertaking. A quick Google search indicated a handful of literature articles using Aspen-Plus to simulate PG of various feeds.

The question of scalability is the one of greatest uncertainty. Clearly the economies of scale favor large scale processing of wastes and biomass for achieving highest efficiency. This is due in measure to the fact that heat losses will account for an increasing fraction of the energy requirement of the plasma gasifier as size decreases. This is a direct consequence of the increase in surface-to-volume ratio as size is reduced. Since the loss of heat through convection and radiation are phenomena that are proportional to surface area, smaller systems become less capable of efficient heat retention. In a survey of the literature (granted a perusing survey), it seems that research plasma gasifier systems are largely batch systems with energy capacities in the 50-100 kW range. A significant line of research would be to study continuously fed gasifiers in the sub-10 kW range in order to learn about downward scalability of the technology implemented in a mode more reflective of the steady-state regime that would be used in a practical system.

High throughput processing (large scale) is more straightforward. Scaling up would be done by simple addition of the highest scale units available. For example, install two 10 MW gasifiers to achieve 20 MW processing.

2. **What research is needed to improve plasma gasification, in particular with respect to compact, small-scale processing of waste and agricultural residue for synthesis gas production?**

As described in the answer above, a scalability study is needed. It is quite possible, based on the limitations of surface-to-volume ratio, that net positive energy efficiency is not possible at lower scales. Although the function of compact waste disposal would still be viable, the ability to serve as a net provider of energy would not be facilitated.

The sensitivity of small-scale systems to feedstock type might be predicted. Higher energy content biomass vs. lower energy content waste feeds may result in very different outcomes such that energy efficiency may be achievable in one and not the other. Factors such as water, inorganic, and metal content may have drastic effects on performance whereas large scale systems appear to be relatively robust in the face of these additional components.

Moreover, it seems that the pre-processing of feedstock could be more critical at smaller scale. For example, chipping and grinding operations to allow the fuel to be adequately

fluidized (suspended) in a smaller reactor would be more important to prevent fouling or plugging of the reaction zone.

3. How “green” is plasma gasification? (How does it compare with other gasification technologies? How does it compare with other low temperature processes for converting cellulose or other organic materials into gas or liquid fuels? What gas cleanup is required? What are the limitations? How could it be improved?)

The notion of “green” relates to energy efficiency, carbon footprint, and sustainability. The most obvious difference between PG and the other gasification technologies is the need for the direct injection of high value (in the sense of cost) energy in the form of electricity. Energy inputs in the thermophysical approaches can take the form of heat which can be generated by combustion of lower value fuels. In the PG case, this will always serve to take a slice out of the net efficiency of the conversion of the fuel into energy. If waste disposal is of primary concern, then production of sufficient energy to allow the process to be self-sustaining without additional energy requirement could be adequate. However, the efficient extraction of energy from, for example, crop-derived biomass may not be adequate in comparison to the other technologies (thermophysical and biochemical).

Gas cleanup depends on the final use of the synthesis gas. If it is sent directly to a combustor for conversion into electricity by a turbine, cleanup would be less exacting than if it were being sent to a Fischer-Tropsch process for the creation of liquid fuels.

The fundamental limitation seems to lie in the attainable efficiency of the PG process given the electrical energy requirement. The data for this efficiency must be critically reviewed for the energy production application when waste disposal is not part of the equation. For mobile, small-scale systems suitable for military forward bases and other lightweight applications, this data is even more critical and is probably not yet available.

379: Response to Queries

Sven Bilén, Steward Kurtz
Penn State University

4. Academic Perspectives

Rather than answer the posed questions separately, permit us to respond more holistically to them. The reason for approaching a response in this manner is the term "plasma gasification" is not a single process and, as such, the unknowns will depend on:

1. Process
    a. Plasma arc (DC and pulsed)
    b. Microwave
    c. Other possible plasma production methods
2. Application
    a. Gasification
        i. Gas is used as a gas
        ii. Gas is further liquefied using a process such as Fischer–Tropsch
    b. Combined heat and power (CHP)
    c. Electric power
3. Feedstock
    a. Type
        iii. Biomass
        iv. Agricultural residue

v. Waste

b. Form

vi. Dry

vii. Liquid

4. System size

a. Industrial scale

b. Small (flatbed truck size)

Plasma gasification systems have been around for many decades and generally have been successfully deployed as larger (industrial scale) systems and, in a few cases, as smaller portable demonstration systems. In order to develop a next generation of plasma gasification systems to meet DoD needs, it is advantageous to be able to model the process(es) at a level of fidelity sufficient to have confidence that the systems designed can scale to the required (low or high) processing volume. Understanding the fundamental processes involved such that systems can be engineered is a critical role that academic partners can play.

Our understanding of other plasma processes is such that we can engineer systems using those plasmas. Plasma modeling and simulation tools have also significantly improved over the past few decades. However, many of the plasma gasification systems in operation today are not fitted with suites of diagnostics that would provide the data needed to verify simulation results. Hence, collecting this data is critical and again, this is role that academia could play as most companies would view this as proprietary. Once models are verified, they can be applied to the engineering of new systems.

The other questions, particularly “how ‘green’ is plasma gasification?” again would depend on addressing the unknowns listed above. If the interest is in the production of syngas, then the make-up (i.e., the “greenness”) of the syngas(es) produced will depend on the process(es) employed as well as the feedstock(s). The systems deployed now often need to be “tuned” to each feedstock, hence limiting the variability of feedstock for cleanest operation. Again, the role that academia can provide here is to provide an evaluative role.

To address the questions of interest and to advance and commercialize the resulting technology, academia can play an important role to provide needed data as well as the role of “trusted agent.” Building a research plasma gasification system to provide the needed data for the development of next generation systems should be considered as an important element of any development program.

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